The role of ecological compensation areas in conservation biological control

Promotor:	
Prof.dr. J.C. van Lenteren	Hoogleraar in de Entomologie

Promotiecommissie:	
Prof.dr.ir. A.H.C. van Bruggen	Wageningen Universiteit
Prof.dr. G.R. de Snoo	Wageningen Universiteit
Prof.dr. H.J.P. Eijsackers	Vrije Universiteit Amsterdam
Prof.dr. N. Isidoro	Università Politecnica delle Marche, Ancona, Italië

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Giovanni Burgio

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to Giorgio

Multaque tum interiisse animantum saecla necessest
nec potuisse propagando procudere prolem.
nam quaecumque vides vesci vitalibus auris
aut dolus aut virtus aut denique mobilitas est
ex ineunte aevo genus id tutata reservans.
multaque sunt, nobis ex utilitate sua quae
commendata manent, tutelae tradita nostrae.
principio genus acre leonum saevaque saecla
tutatast virus, vulpis dolus et gfuga cervos.
at levisomma canum fido cum pectore corda
et genus omne quod est veterino semine partum
lanigeraeque simul pecudes et bucera saecla
omnia sunt hominum tutelae tradita, Memmi.
nam cupide fugere feras pacemque secuta
sunt et larga suo sine pabula parta labore,
quae damus utilitatiseorum praemia causa.
at quis nil horum tribuit natura, nec ipsa
sponte sua possent ut vivere nec dare nobis
praesidio nostro pasci genus esseque tatum,
scilicet haec aliis praedae lucroque iacebant
indupedita suis fatalibus omnia vinclis,
donec ad interutum genus id natura redegit. (855-877)

Lucrezio (I secolo A.C.), *De rerum natura, libro V, vv 855-877, Oscar Mondadori.*

And many races of living things must then have died out and been able to beget and continue their bred. For in the case of all things which you see breathing the breath of life, either craft or courage or else speeds from the beginning of its existence protected and preserved each particular race. And there are many things which, recommended to us by their useful services, continue to exist consigned to our protection. In the first place the fierce breed of lions and the savage races their proneness to flight. But light-sleeping dogs with faithful heart in breast and every kind which is born of the seed of beasts of burden and at the same time the woolly flocks and the horned herds are all consigned, Memmius, the protection of man. For they have ever fled with eagerness from wild beasts and have ensued peace and plenty of food obtained without their own labour, as we give it in requital to their useful services. But those to whom nature has granted none of these qualities, so that they could either live by their own means nor perform for us any useful service in return for which we should suffer their kind to feed and be save under our protection, those, you are to know, would lie exposed a prey and booty of others, hampered all in their own death-bringing shackles, until nature brought that kind to utter destruction.

Lucrezio (I century B.C.), *De rerum natura, 855-877, translated by H.A.J. Munro, Cambridge, Deghton Bell and co, London, George Bell and sons, 1886.*

Contents

Abstract

Ecological compensation areas (ECAs), defined as all natural vegetation and non-crop plants within the rural landscape, are considered an important tool in multifunctional agriculture. In particular, ECAs are crucial in enhancing functional biodiversity for pest suppression and for the conservation of rare species. In my PhD thesis I focused on the role of ECAs on functional biodiversity, which is associated with the ecological services employed by the beneficial fauna. Within multifunctional agriculture, functional biodiversity is particularly aimed at establishing strategies for farmers to enhance ecosystem functioning for pest suppression and for conservation of insect diversity.

I performed several case-studies about insect conservation within the rural landscape of the Po Valley in northern Italy. First, I carried out two case-studies at the farm-scale, which are presented in the first two sections of the thesis that address (i) the role of ECAs on generalist predators and (ii) the role of ECAs and flowering plants on parasitoids of leafminers. Then, in the last part of the thesis (section 3), I report a case of insect conservation at the landscape-scale, which involved the sampling of different insect bioindicators, like syrphids, carabids, butterflies and sawflies.

The research described in the first two sections, resulted in the identification of many non-crop plants within ECAs that play an important role in the conservation of beneficial insects, including generalist predators and parasitoids. Knowledge about the role of non-crop plants on the multiplication, life cycle and population dynamics of these beneficial arthropods can be helpful to select weeds, trees and shrubs, in order to restore degraded agroecosystems. In the thesis I provide detailed lists of non-crop-plants and related beneficial insects that will assist in the implementation of management techniques of non-crop plants within ECAs.

In the third section, I was able to demonstrate that each insect group displayed different biodiversity patterns in relation to the different landscape/micro-habitat categories. Bioindicators like syrphids and carabids were strongly affected by the landscape complexity, while butterflies were mainly influenced by the micro-habitat characteristics. I discuss the role of these insect groups as landscape/micro-habitat indicators and I provide faunistic list of species which may be helpful to compile regional lists for studies on insect conservation. Next, I discuss the importance of assigning a "*functional meaning*" to faunistic lists of insects in a landscape management approach. In order to develop this aspect, I used an expert system, called Syrph the Net, which is a tool that uses the so-called *biodiversity maintenance function* to explore elements of site quality and site management.

In all the sections, I discuss the importance of sampling techniques for quantification of insect diversity. In conclusion, my thesis project demonstrates the importance of ECAs on insect conservation and biodiversity, and also provides information about management strategies for non-crop plants to improve conservation biological control and conservation of rare insect species.

Chapter 1

General introduction

Insect conservation and the rural landscape: an overview of the study with particular reference to the local biodiversity within the study-area

Introduction

In this thesis, I address the potential role of ecological compensation areas for realizing conservation biological control. Conservation biological control refers to the use of indigenous predators and parasitoids, usually against native pests. In conservation biological control, various measures are implemented to enhance the abundance or activity of the natural enemies, including manipulation of the crop microclimate, creation of overwintering refuges, increasing the availability of alternative hosts and prey, and providing essential food resources such as flowers for adult parasitoids and hoverflies (Barbosa, 1998; van Lenteren, 1998; Landis *et al.,* 2000; Wratten et al., 2003). Here, I will limit myself mainly to one aspect of conservation biological control: the contribution of natural enemies from non-crop habitats to biological control of pests in agroecosystems. The type of non-crop habitats that are considered in this thesis are ecological compensation areas (ECAs, see below) in the Po valley near Bologna, Italy. In this thesis I will use examples from two natural enemy–herbivore systems (aphids-coccinellids, and agromyzid leafminers-parasitoids) to illustrate the importance of ECAs for conservation biological control. However, in the last part of the thesis, I will discuss insect functional biodiversity at a landscape scale, and contribute to the complex and currently very important topic of the value and use of biological indicators. In this part, I will analyse principally data concerning syrphids, but I will compare other insect groups like carabids, butterflies and symphytic Hymenoptera with the data from syrphids.

First, I will shortly introduce my thesis project. Next I will describe the study area. This is followed by the aims of the research and the outline of the thesis.

Quality of the rural landscape, insect conservation and biological control

There is an increasing body of evidence suggesting that connectivity and quality of habitats have a significant effect on survival of plant and animal species in agricultural landscapes (see papers in Rossing et al., 2003). Authors in Rossing et al. (2003) proposed the notion of "green-blue veins", the network of roadsides, ditches, hedgerows and other non-crop elements, that can be seen as reservoirs and corridors of biodiversity in rural landscapes. With the emergence of the science of conservation biology, the problem and the study of biodiversity became one of the key points of interest in biology, and it also strongly involves public opinion (Samways, 1994). Next to pure scientific aspects of conservation biology, also societal and applied aspects play an increasing role, for example in discussions concerning (1) the quality of the rural landscape, and (2) the potential contribution of biodiversity of (semi-) natural areas to the ecosystem function of biological control. As a result of these discussions, we can now perceive that enhancing plant and animal diversity has become an aim of agricultural policy in various countries (see papers in Rossing et al., 2003). Moreover, also in modern integrated pest management (IPM) strategies, the "ecological perspective" including ecosystem functions of native biota has become an important aspect in the study of outbreaks of pests in agroecosystems (Barbosa and Schultz, 1987; Waage, 1996; Lewis et al., 1997, van Lenteren, 1998).

The landscape in which agriculture currently takes place is characterized by (1) low species diversity, (2) plants with little architectural complexity, and (3) plants and animals that are short-lived and that have a high fecundity, a relatively good dispersal capacity but a poor competitive ability (Bukovinszky, 2004). Further, many agroecosystems are dominated by weeds, insects and pathogens that are highly adapted for rapid colonization and population increase. Plants with simple architectures have fewer associated species of insects (pests and beneficials) than diverse and architecturally complex plant communities (Landis and Marino, 1999; 1999bis). As a consequence of these low-diversity plant and herbivore communities, agroecosystems often have strongly impoverished natural enemy communities when compared with natural ecosystems (Landis *et al*., 2000). However, the areas adjacent to crop fields are usually less disturbed and architecturally more complex, with a richer and more stable natural enemy fauna that can provide source populations of beneficial arthropods to promote pest management. But it should be realized that these extra-field communities may also act as a reservoir for pest species (e.g. Winkler, 2005). Although the importance that non-crop habitats may play in the provision of natural enemies has been stressed in many papers (see e.g. Landis *et al.* 2000), there is currently still very limited experimental insight in how this functions, and also experimental evidence for improved conservation biological control as a result of increased biodiversity is rare.

Conservation biological control involves, among others, environmental manipulation to enhance the fecundity and longevity of natural enemies, modify their behaviour and provide shelter from adverse environmental conditions (van Lenteren, 1980; Barbosa, 1998; Wratten et al., 2003; Landis et al., 2000). These strategies, included as elements of landscape management programmes, comprise the maintenance and management of ecological infrastructures such as ecological compensation areas (ECAs), which can be defined as all natural vegetation and non-crop plants within the rural landscape. ECAs are crucial in enhancing functional biodiversity for pest suppression and for the conservation of rare species (e.g. Boller et al., 2004; Rossing et al., 2003).

Biological diversity – or biodiversity – is a very complex topic, covering many aspects of biological variation (e.g. Gaston, 2000; Harrison et al., 2005). In the definition of biodiversity, scientists include not only living organisms and their complex interactions, but also interactions with the abiotic (non-living) elements of the environment. Many definitions emphasizing one aspects or another of biological variation can be found throughout the scientific literature (e.g. Magurran, 1988; Gaston, 1996, Gaston, 2000; Harrison et al., 2005). Functional biodiversity can be defined as "the ecological and evolutionary processes that sustain the variety of life". In applied entomology and landscape management, functional biodiversity is associated to the ecological services employed by the beneficial fauna, including predatory and parasitic insects (Altieri, 1999). Within agroecosystems, functional biodiversity is aimed at establishing strategies for farmers to enhance ecosystem functioning for pest suppression (Rossing et al., 2003).

ECAs are considered an important tool in multifunctional agriculture, i.e. agriculture that aims to fulfill more goals than just the provision of food. Boller et al. (2004) give very practical descriptions and specifications of ECAs and provide examples of management techniques of ECAs at farm level.

Based on the general lack of reliable experimental insight in how ECAs may contribute to conservation biological control, there is a strong need for studies in this research area. It has recently been shown that the selective enhancement of natural enemies requires in-depth knowledge of the biology of the species in the ecosystem (e.g. Bukovinszky, 2004; Winkler, 2005). Inappropriate subsidy of resources may increase pest pressure, either by disrupting the activity of natural enemies, or by benefiting the antagonists of natural enemies. In annual cropping systems, biological control may become active too late because natural enemies arrive in the habitat when pest populations have already built up (van Lenteren, 1980). Synchronizing natural enemy and herbivore populations may circumvent this problem (Bukovinszky, 2004). Practices to syncronize herbivores and natural enemies include management of ECAs. A crucial role to realize synchronization is represented by non-crop plants, which may strongly influence the movements of "cyclic colonizer" natural enemies in the agroecosystem (Landis et al., 2000).

The few examples of ECAs indicate that rural management strategies need to be developed that carefully take the regional biogeography and the local landscape characteristics into account.

Study-area: the rural landscape of the Po Valley in northern Italy

The Po Valley in northern Italy is a very fragmented region which has been strongly influenced by man for many centuries. In the Italian North-east lowlands, the agroecosystem structure and landscape designs are a blend of ancient agronomic practices and very modern agricultural trends (Figure 1) (Paoletti and Lorenzoni, 1989). The crops that are grown vary among localities, but in general the more important arable crops are wheat, sugar-beet, corn, and alfalfa. Important open-field vegetables are tomato and lettuce, and fruit orchards mainly consist of pear, peach, apple and grape. In this landscape, hedgerows, which are often an element of ecological corridors, consist of wild plants and plants introduced by farmers. Today there are very few remains of the forests which probably completely covered this region in the past. In Italy, research on landscape management has developed only very recently and published information is still rare. However, a good example of this kind of studies is provided by Paoletti and Lorenzoni (1989), who analysed the interactions between non-crop lands and agroecosystems, including woodland, hedgerows and forest relicts in northeastern Italy. Further, overviews of the farm and landscape interventions in the rural landscape of Emilia-Romagna (northern Italy) are given by Ferrari et al. (1998), Burgio et al. (2000) and Morisi (2001). In addition, recently a review of the studies on vegetation biodiversity and arthropod pest management in Italy was published by Altieri et al. (2003). These early studies make clear that much knowledge and insight still has to be developed before ECAs can be applied effectively.

One of the first Italian studies, which was started in the early 1990s, concerns a rural improvement programme in Emilia-Romagna (Emilia-Romagna Region Report, 2006; Burgio et al., 2006). The local government of Emilia-Romagna has acknowledged the CEE Regulation 2078/92 by applying the "*Pluriennial Local Program*". According to this agro-environmental program, the Emilia-Romagna Region established general aims and an action programme to apply to rural landscapes (Emilia-Romagna Region Report, 2006). Within this complex programme, particular attention was directed to the restoration of rural landscapes and the improvement of plant and animal biodiversity. A specific activity involved a reduction of chemical pesticides on IPM farms, and the introduction and maintenance of organic farms. Between 1993-1999 the programme was put into practice on about 232,000 hectares (19.5% of all fields in the area), involving 13,396 farms (11.1% of all farms in the region). The programme was applied widespread in the Region (Burgio et al., 2006). Many efforts considered the recovery and enhancement of natural environments within rural landscapes and the creation of ecological networks by constructing and improving ecological corridors (Morisi, 2001). Agro-environmental measures in rural landscapes concerned also the planting of hedgerows, partly as ecological corridors, and the conservation of existing (semi-natural ecosystems like marshes, ponds, wetlands and woods. All these interventions were not only carried out to re-establish and to augment plant and animal biodiversity, but also to improve conservation biological control (see below).

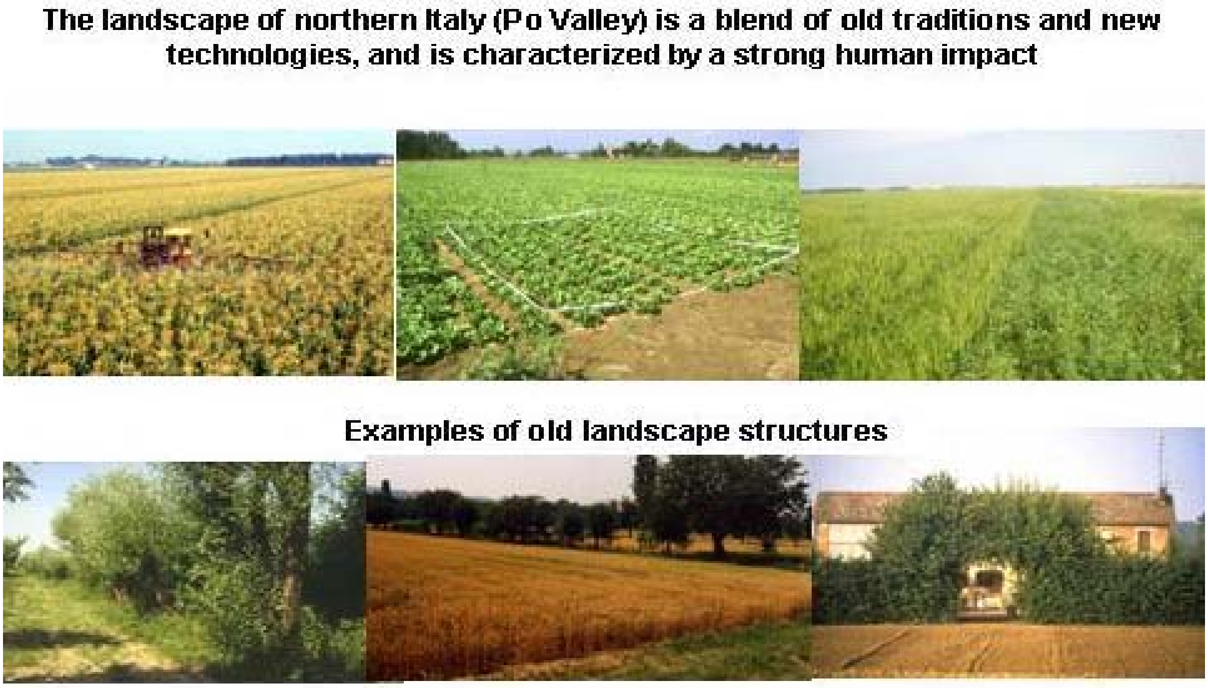

Figure 1. Examples of old and recent landscape structures in the Po valley, Italy

Local biodiversity

An increasing body of evidence suggests that connectivity and quality of habitats have a significant effect on the maintenance of species in agricultural landscapes (e.g. Rossing et al., 2003). Habitat destruction and fragmentation are considered to be the major negative factor in landscape management, because they strongly affect the occurrence of species and thus of biodiversity in a negative way (Tscharntke and Brandl, 2004). Biodiversity in fragmented landscapes consists of two components: local richness of the habitat (alpha diversity) and dissimilarity (beta diversity) between local habitats. Together, alpha and beta diversity determine the overall species richness (gamma diversity) across the landscape (Magurran, 1988; Tscharntke and Brandl, 2004). It appears from studies on local-regional richness relationships that species richness on the landscape scale is usually higher than species richness on the habitat scale, and that species richness within habitats (local richness) is correlated with the species richness of the landscape (regional richness) (Tscharntke and Brandl, 2004).

Rural landscapes and biodiversity patterns may vary considerably in relation to geographic area, climatic condition, crop system, farm and landscape management, and pest management strategies. For example, in a study aimed in enhancing biodiversity on Dutch arable farms, Manhoudt (2006) focused on biodiversity and management of ditch banks, the most common kind of semi-natural habitat on farms. This study provides information about active ecological management of ditch banks aimed at reducing nutrient input and vegetation biomass. This study also gives examples of local management of biodiversity, which takes the ecological and rural characteristics of a specific landscape into account.

Recently, within Europe, an effort was made to collect success stories of landscape management projects for functional biodiversity (de Snoo et al., 2006). The paper reported projects employed in United Kingdom, Switzerland, The Netherlands, Italy and Germany. A number of indicators was used belonging to the "people", "planet" and "profit" domains. In this effort, also aspects like the increase of biodiversity and the increase of beneficial arthropods were investigated. For example three of the projects had a direct focus on the enhancement of functional biodiversity at local scale. In general, indicators belonging to the "planet" dimension (i.e. reduction of pest populations, increase of beneficial arthropods, increase of biodiversity and reduction of water and soil contamination) received much attention in these studies. It appeared that particularly the enhancement of landscape management for biological conservation reasons was successful in these projects. Indicators belonging to the "people" dimension (i.e. acceptance of functional biodiversity by farmers and advisors, number of farmers involved, network of stakeholders, acceptance of public, influence on policymakers) received more attention than initially foreseen. Some indicators belonging to the "profit" dimension, like cost/benefit analyses of landscape management, and cost/benefit analyses of ECAs, were studied to a lesser extent. The analysis presented by de Snoo et al. (2006) can be seen as a first step in evaluating landscape management projects and it provides also examples of success indicators for each of the domains of sustainable development.

It is crucial to collect information on a local scale, because the role of functional biodiversity and landscape management on conservation biological control can often not be generalized to higher scales. Delucchi (1997), for example, reports that the effect of certain conservation practices like flowering field edges differ consistently among countries. Therefore, in studies aimed at improvement of the quality of the rural landscape, it is important to select effective bio-indicators to determine effects and for evaluating the quality of landscape management at different scales (i.e. the field, the farm and the landscape) for each study area.

Also for biodiversity conservation purposes, recording of rare arthropod species and understanding the role of "island habitats" on the maintenance of these rare species is of great importance. Finally, a thorough evaluation of ECAs on natural enemy biodiversity is crucial, because only then a first attempt can be made to estimate the role of ECAs for improvement of conservation biological control.

Research aims

The general aims of this PhD project are:

1. to study and understand the role of Ecological Compensation Areas (ECAs) on the population development of beneficial insects at farm and landscape scale

2. to design an "advanced crop protection model" which could, taking into account the role of the natural vegetation, result in improved conservation biological control in combination with having positive effects on biodiversity at a local landscape scale
3. to compare and select insect species that may function as bioindicators for "landscape management quality" in northern Italy
4. to identify plant species in the natural vegetation which enhance biological control of insect pests.

The specific aims of this PhD project are:

1. to determine the role of ECAs on generalist predators, with particular reference to coccinellid predators (Coleoptera: Coccinellidae)
2. to evaluate the role of non-crop (flowering) plants for conservation and augmentation of parasitoids of leafminers (Diptera: Agromyzidae) on vegetable crops
3. to compare the usefulness of different species of insects (including Lepidoptera, Coleoptera Carabidae, Diptera Syrphidae, and Hymenoptera Symphyta) as bioindicators for evaluation of the quality of rural landscapes and the conservation status of the insect fauna in these landscapes.

Outline of this thesis

In **chapter 1**, I review the topics of my thesis project, including the research aims. In sustainable agriculture, the management of ecological infrastructures, or, more specifically for this project, ecological compensation areas, within the rural landscape play a crucial role in enhancing functional biodiversity for pest suppression and for the conservation of rare species. In multifunctional agriculture, i.e. agriculture that serves more goals than purely the production of food, it is crucial to understand the role of non-crop plants at a local scale, in order to select strategies and methods to improve the conservation of the beneficial fauna in the specific habitat - and crop system.

In the **first section** of the thesis (**chapters 2** and **3**), I discuss the role of ecological functions of ecological infrastructures with respect to predator populations. I have selected beneficial Coccinellidae for this case study, and I study which plants in the ecological infrastructure play a role in the conservation of these beneficials. I study the relationships between non-crop plants (including hedgerows, shrubs and weeds) and coccinellid predator populations. I analyse the faunistic data of insect predators taking into account the historical data about the population dynamics of beneficials on arable and vegetable crops in my study area. I have used the faunistic and ecological data of the predatory coccinellids to show the phenology of these coccinellids in the ecological infrastructures. In this way, I obtained practical information about the rational management of non-crop areas to conserve or augment beneficial coccinellid populations.

In the **second section**, I study the role of weeds and non-crop plants on natural enemies that play a role in conservation biological control of agromyzid pests. In **chapter 4**, I analyse the tritrophic interactions among weeds–agromyzid leafminers–and parasitoids, and I identify the non-crop plants that play a crucial role in conservation of natural enemies of *Liriomyza huidobrensis*. This leafminer is the most important economic pest among the leafminers that occur in my study area. I also study how to manage this pest on lettuce in order to improve conservation biological control. To be able to do this, I first had to identify sampling methods for monitoring populations of leafminers and parasitoids. In **chapter 5**, I demonstrate that binomial sampling and sequential sampling by the "stop lines" method are practical tools to monitor the leafminer and parasitoid populations. This composite sampling method is easy and time-saving. It also permits me to obtain information on the efficacy of conservation biological control on lettuce. In **chapter 6**, I investigate the role of an "annual flowering plant mixture" on the parasitism of leafminers in a lettuce crop. I demonstrate that flowering plants enhance the activity of parasitoids, particularly the activity of the less abundant species in human-influenced habitats. This enhanced activity of parasitoids can be of great ecological value in stabilising trophic networks in lettuce, a crop usually characterised by a very short production cycle and many pesticide treatments. Evaluation of the results obtained in this chapter leads to the conclusion that rational management of weeds and flowering plants can be recommended to improve conservation biological control of leafminer pests.

After presenting these "farm-scale" cases of economic importance of ecological infrastructures for sustainable pest management in my region, I studied insect functional biodiversity at the landscape scale, the results of which I present in the **third section** of my thesis. Due to the growing interest in the role of functional biodiversity in rural landscapes, it is important to determine effective biological indicators in order to be able to evaluate the quality of ecological interventions in this rural landscape. I compare different functional insect bioindicators, that may contribute to the compilation of a data bank for environmental evaluations. I compare nine sites within my study region characterised by different ecological complexity and different plant typology, and I use a composite monitoring system that involves different sampling methods. In **chapter 7** I use syrphids (Diptera) as biological indicators and I try to apply a method called "Syrph the Net" in order to obtain information on the quality of a rural landscape by using a data matrix of this group. In **chapter 8** I analyse faunistic data of carabids (Coleoptera), butterflies (diurnal Lepidoptera) and symphytic Hymenoptera, and compare their relative efficiency as bioindicators. Finally, I compile a list of the indicator fauna in a rural landscape, which includes many rare species and which can be used as data bank for environmental evaluations at a local scale.

In **chapter 9**, the general discussion, I review the most important results from my research project. Finally, I discuss the importance of the present results in the context of sustainable agriculture. In particular I evaluate the role of non-crop plants on beneficials populations in the studied systems and I try to draw overall conclusions on the role of ecological infrastructures on augmentation of biological control and conservation of rare insect species.

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Section 1

Analysis of the role of non-crop plants on the conservation of predators

Chapter 2
The effect of ecological compensation areas on predator populations: an analysis of biodiversity and phenology of Coccinellidae (Coleoptera) on non-crop plants within hedgerows in northern Italy

Chapter 3
The effect of ecological infrastructures on Coccinellidae (Coleoptera) and other predators in weedy field margins within northern Italian agroecosystems

Chapter 2

The effect of ecological compensation areas on predator populations: an analysis of biodiversity and phenology of Coccinellidae (Coleoptera) on non-crop plants within hedgerows in northern Italy

Abstract

The role of natural vegetation, including trees, shrubs and weeds, in supporting predatory insects with particular reference to coccinellids, was investigated in a two-year field study. Sampling was carried out by mechanical knock-down (MKD) and visual inspection (VIS) of hedgerows in northern Italy (Bologna province). Among trees and shrubs, *Euonymus europaeus* L. (spindle-tree) and *Prunus spinosa* L. (blackthorn) showed the highest number of predatory species, followed by *Crataegus monogyna* Jacques (hawthorn), *Populus* sp. (poplar), *Cornus sanguinea* L. (dogwood) L. and *Corylus avellana* L. (hazel). *Salix alba* L. (willow) and *Pyrus pyraster* Burgsdorf (wild pear) were characterised by the lowest level of predator diversity. Coccinellidae represented the most abundant family of insect predators on trees, shrubs and weeds. Eggs and/or larvae of Coccinellidae were found in all the tree and shrub species sampled with the exception of *Sambucus nigra* L. (elder). Data demonstrate that some tree and shrub species can provide shelter for adult ladybirds, mainly in late summer, when many crops in northern Italy are harvested.

A list of the coccinellid species, including relative abundance of the most important plant species, is provided. The number of species sampled by MKD on hedgerows was higher than those sampled by VIS. Among the weeds, *Cirsium* sp., *Rumex* sp. and *Urtica dioica* L. (stinging nettle) supported the reproduction of coccinellids. Only adults of coccinellids were found on *Daucus carota* L., *Amaranthus retroflexus* L., *Dipsacus sylvestris* Hudson, *Arctium* sp.*, Crepis* sp.*, Picris* sp.. Correspondence analysis was used for the ordination of both plant and coccinellid species and it was performed on the matrix of the data collected by VIS. The role of hedgerows and weeds in landscape management is discussed. Local biodiversity can be conserved and improved by increasing "island" habitats like hedgerows and field margins.

Introduction

Conservation biological control involves environmental manipulation to enhance the fecundity and longevity of natural enemies, modify their behaviour and provide shelter from adverse environmental conditions (Wratten *et al.*, 2003). These strategies include the maintenance of ecological compensation areas (ECAs) and are crucial in enhancing functional biodiversity for pest suppression (Rossing *et al.*, 2003). Moreover, with the emergence of the science of conservation biology, the problem and the study of diversity has become one of the central interests of research in biology, and involves also public opinion (Samways, 1994).

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Many authors have pointed out the potential importance of vegetational diversity in agroecosystems in order to enhance the populations of beneficial arthropods in crops and thus contribute to controlling arthropod pests (Pimentel, 1960; van Emden and Williams, 1974; Risch, 1987; Ferro, 1987). Several reviews have treated published case studies about the effects of landscape management on populations of beneficials (Altieri and Letourneau, 1982; Sheenan, 1986; Russell, 1989; Van Emden, 1990; Delucchi, 1997; Altieri, 1999; Andow, 1991; Paoletti, 1999; Landis *et al.*, 2000; Altieri, 2003). Recently, a study group on "Landscape Management for Functional Biodiversity" within IOBC/WPRS was founded with the aim to provide a platform for discussing research results, research agendas and methodological aspects related to functional biodiversity at different spatial and temporal scales (Rossing *et al.*, 2003).

In many countries the promotion of the enhancement of vegetational diversity has become an aim of agricultural policy (Rossing *et al.*, 2003). In Italy, hedgerow planting and natural vegetation management have been widely used in the last twenty years, especially in orchards, by agreement of local governments. The Emilia-Romagna Region is applying the

Table 1. Sampling sites and the most abundant plants at these sites.

Farm	Year	Locality	Crops	Most abundant plants inside ecological compensation areas
Guazzaloca	1995	Crevalcore (BO)	Arable crops	*Prunus spinosa*, *Populus* spp., *Fraxinus* spp., *Morus nigra*, *Ulmus* spp., *Acer campestre*
Azzoguidi	1995	Sala Bolognese (BO)	Orchard	*Prunus spinosa*, *Ulmus minor*, *Quercus* spp., *Sambucus nigra*, *Robinia pseudoacacia*, *Euonymus europaeus, Cornus sanguinea*, *Fraxinus* spp., *Crataegus monogyna*, *Urtica dioica*
Maieutica-Bora	1995	S. Giovanni in Persiceto (BO)	Orchard	*Crataegus monogyna*, *Prunus spinosa*, *Ulmus* spp., *Acer campestris*, *Sambucus nigra*, *Rosa canina*, *Cornus sanguinea*, *Populus* spp., *Urtica dioica*, *Cirsium* spp., *Rumex* spp.
Gubellini	1995	Bologna	Orchard	*Salix alba*, *Sambucus nigra*, *Robinia pseudoacacia*, *Urtica dioica*, *Cirsium* spp., *Rumex* spp.
Cà il Rio (site 1)	1995	Castel S. Pietro (BO)	Arable crops	*Morus nigra*, *Ulmus* spp., *Prunus spinosa*, *Robinia pseudoacacia*, *Populus* spp., *Urtica dioica*, *Cirsium* spp., *Rumex* spp.
Cà il Rio (site 2)	1997	Castel S. Pietro (BO)	Arable crops	*Euonymus europaeus, Corylus avellana*, *Crataegus monogyna*, *Cornus sanguinea*, *Urtica dioica*, *Cirsium* spp., *Rumex* spp.
Cà il Rio (site 3)	1997	Castel S. Pietro (BO)	Arable crops	*Populus* spp., *Euonymus europaeus, Crataegus monogyna*, *Cornus sanguinea*, *Pyrus pyraster*, *Corylus avellana, Urtica dioica*, *Cirsium* spp., *Rumex* spp., *Dipsacus sylvestris*
Forni	1997	S. Giovanni. in Persiceto (BO)	Arable crops	*Euonymus europaeus*, *Crataegus monogyna*, *Prunus spinosa*, *Cornus sanguinea, Urtica dioica*, *Cirsium* spp., *Rumex* spp., *Dipsacus sylvestris, Picris* spp., *Crepis* spp.
Morisi	1997	S. Giovanni in Persiceto (BO)	Arable crops, orchard	*Crataegus monogyna*, *Prunus spinosa*, *Cornus sanguinea, Corylus avellana, Cirsium* spp., *Rumex* spp., *Dipsacus sylvestris, Picris* spp., *Crepis* spp.
Breveglieri	1997	Calderara di Reno (BO)	Arable crops	*Populus* spp., *Corylus avellana*, *Cirsium* spp., *Rumex* spp., *Picris* spp., *Crepis* spp.

European community agroenvironmental measures within the law n. 2078/92 at a local scale and funded plantation of hedgerows to realize an ecological network in the rural landscape (Maini, 1995; Burgio *et al*., 2000; Morisi, 2001; Regione Emilia-Romagna, 2001). In Italy some data are available on the management of vegetational and animal biodiversity to improve control of arthropod pests (reviewed by Altieri *et al*., 2003). There is now a need to expand these studies to other trophic systems and crops, because there are very few examples of biodiversity management at a lanscape scale (Morisi, 2001; Sciarretta *et al*., 2003). However, in other countries this landscape scale approach is studied more extensively (Holland and Fahrig, 2000; Marino and Landis, 1996; Rossing *et al*., 2003).

In Italy there is a growing interest to investigate and understand the role of ECAs and functional biodiversity in rural landscapes. Detailed knowledge of the tri-trophic relations between plants, herbivores and beneficials is of basic importance for ECA management in order to control arthropod pests and to select, for example, the plant species that are most suited to augment the beneficial fauna. Judicious management of ECAs is important also in order to prevent the damage of arthoropod pests on crops (Altieri and Letourneau, 1982; Andow, 1991; Delucchi, 1997; Tavella *et al*., 1996; Ferrari e Boriani, 2000; Altieri *et al*., 2003).

The aims of the research presented in this chapter were: 1) to study the role of natural vegetation, including shrubs, trees and weeds on the cycle and phenology of beneficial predators; 2) to examine the biodiversity of predators on different plant species; and 3) to gain preliminary indications on how to manage ECAs in order to enhance populations of beneficial organisms. In order to be able to perform this study, sampling techniques had to be selected to monitor predator populations. Particular attention was given to Coleoptera Coccinellidae for their importance in controlling aphid populations on many crops grown in northern Italy (Ferrari *et al*., 1996; Molinari *et al*., 1998; Burgio *et al*., 1999).

Materials and Methods

Selection of sampling areas and sampling methods.

Typical hedgerows were selected on five (1995) and four farms (1997) located in the Bologna province (northern Italy). We selected ECAs that were representative of the rural landscape of our region, including hedgerows with similar vegetation characteristics and structure to reduce the biological variability due to the age and plant composition of hedgerows. On all the farms, Integrated Pest Management was applied. A list of the sites sampled, including the main characteristics of the farms, is presented in Table 1. Plants that are most representative for the local rural landscape were selected for sampling, taking into account the preliminary data collected by Nicoli *et al.* (1995), Boriani *et al.* (1998), Burgio *et al.* (2000), and Celli *et al.* (2001).

In each ECA the most abundant trees, shrubs and weeds were sampled. Tree and shrub canopies were sampled by mechanical knockdown (MKD) every 14 days, and by visual inspection (VIS) every 7 days. MKD consisted of beating branches with a stick and the insects falling into a 90 cm diameter funnel were collected and examined in the laboratory. Plants of each species was beaten 100 times, sampling five branches per tree or shrub. Plants and branches were randomly selected for each sampling date. Trees and shrubs were monitored by VIS through random selection of 100 branches per plant species in each hedgerow. Branches were classified into four classes of aphid density (0, 1-10, 11-100, >100);

aphids are one of the more abundant phytophagous insects on hedgerows in northern Italy (Ferrari *et al.* 1999). Also all stages of predators were counted.

Weed species were randomly sampled by VIS, counting the insect predators and estimating the aphid infestation on a variable number of plants (20-100). The number of stems sampled was decided according to the density of the plant species and to the abundance of insects during preliminary sampling.

Data analysis

In 1995 insect predators were identified to family, in 1997 they were identified to species or genus. The phenology of predators was analysed by data collected with VIS. Relative abundance of the families of predators on each plant species was calculated for the 1995 and 1997 data. Biodiversity of predators for each plant species was calculated with the Shannon's index (H') on data collected by MKD in 1997. As dominance measure, Berger-Parker's index *d* was calculated (Magurran, 1988). As with other dominance measures, the reciprocal form of *d* was adopted so that an increase in the value of the index is correlated with an increase in diversity and a reduction in dominance.

The jack-knifing technique was used in order to improve the estimate of H' and *d* (Magurran, 1988).

Correspondence analysis was used to ordinate the plant species on the basis of the abundance of coccinellid species recorded by visual inspection, on a matrix ***p*** x ***n***, where ***p*** are coccinellid species and ***n*** are plant species. In our case this method was calculated on a ***10*** x ***36*** matrix. This ordination method can be used on data presented as a two-way table of measures of abundance, with the rows corresponding to one type of classification (*coccinellid species*) and the columns to a second type of classification (*plant species*) (Manly, 1994). The aim of this multivariate method was to associate plant species to relative abundance of coccinellids, in other words, to give an ordination of both plant and coccinellid species at the same time.

Results and discussion

Tables 2 and 3 summarise the relative abundance (%) of the families of predators on trees and shrubs sampled by MKD in hedgerows in 1995 and 1997. Coccinellids formed the dominant group and in 1997 this family showed a relative abundance of 67 and 71%, on *Prunus spinosa* L. (blackthorn) and *Cornus sanguinea* L. (dogwood), respectively. In 1995, the relative abundance of Miridae and Chrysopidae together was 34 and 20%, respectively, on *Salix alba* L. (willow) and *Sambucus nigra* L. (elder). Cantharidae and Forficulidae together were more abundant in 1997, with a relative abundance of 37% and 20% on *Populus* spp. (poplar) and blackthorn, respectively.

A comparison of the biodiversity of predators collected by MKD among the different trees and shrubs species in 1997 is shown in Table 4. Shannon's indices and dominance indicators were calculated by means of the jack-knife technique in order to improve the estimate of replicated samples, with the exception of pear which was sampled on one site only. Predator diversity for trees and shrubs is summarised in Table 4. *Euonymus europaeus* L. (spindle-tree) and *P. spinosa* were richest in predator diversity, followed by *Crataegus monogyna* Jacq. (hawthorn), *Populus* sp., *C. sanguinea* and *Corylus avellana* L. (hazel). *S. alba* and *Pyrus pyraster* Burgsdorf (wild pear) showed the lowest level of biological diversity.

Coccinellidae formed the most abundant family; a list of the species sampled by MKD

Table 2. Relative abundance (%) of predators on trees and shrubs sampled by mechanical knock down (MKD) in hedgerows (1995) from the beginning of April to the end of September. Data pooled for all sampled sites.

	Salix alba	*Crataegus monogyna*	*Prunus spinosa*	*Populus* spp.	*Ulmus minor*	*Sambucus nigra*
Coccinellidae	35.1	13.4	26.7	59.5	22.4	43.5
Hemerobiidae	1.5	3.6	0.8	0.8	2.8	1.4
Chrysopidae	15.5	12.5	18.8	13.6	18.4	20.3
Syrphidae	1.1	0.9	3.3	0.0	0.9	2.9
Anthocoridae	10.8	0.4	8.5	6.6	2.8	5.8
Nabidae	1.5	24.2	8.4	2.3	3.4	4.3
Miridae	34.5	5.4	10.8	1.7	24.5	18.8
Carabidae	0.0	7.2	4.3	4.1	5.9	1.4
Cantharidae	0.0	0.0	8.8	4.2	5.8	1.4
Forficulidae	0.0	23.7	7.5	6.8	12.8	0.0
Staphylinidae	0.0	8.5	2.0	0.4	0.3	0.0

Table 3. Relative abundance (%) of predators on trees and shrubs sampled by mechanical knock down (MKD) in hedgerows (1997) from the beginning of April to the end of September. Data pooled for all sampled sites.

	Salix alba	*Corylus avellana*	*Crataegus monogyna*	*Prunus spinosa*	*Cornus sanguinea*	*Euonymus europaeus*	*Populus* spp.	*Pyrus* sp.
Coccinellidae	66.41	71.67	65.20	67.14	72.48	67.29	52.37	48.94
Hemerobiidae	0.76	0.40	0.00	0.35	0.63	0.00	0.00	0.00
Chrysopidae	0.76	1.20	2.10	4.59	2.73	1.25	2.21	1.42
Syrphidae	0.00	0.32	0.38	2.12	0.00	1.04	0.32	0.00
Anthocoridae	1.52	1.44	9.75	1.40	4.41	1.67	1.58	7.09
Nabidae	1.52	4.41	3.82	0.35	7.35	3.54	0.63	0.00
Miridae	3.05	1.85	2.10	2.12	1.26	1.25	1.90	1.42
Carabidae	3.05	0.16	0.00	0.71	0.42	0.83	0.32	0.00
Cantharidae	19.80	3.85	2.10	1.06	1.05	7.71	36.91	33.33
Forficulidae	6.87	13.32	14.53	19.43	8.61	14.58	3.15	7.80
Staphylinidae	0.00	1.36	0.00	0.71	1.05	0.62	0.63	0.00

Table 4. Shannon's index (H') and Berger-Parker's index (*d*) of predators sampled on hedgerow (1997) by mechanical knock down (MKD). Data pooled for each farm. H' and *d* were calculated by Jack-knifing technique on samples of different farms (Magurran,1988) except for pear.

	All predators			Coccinellidae		
	No species	H' (±se)	*d* (±se)	No species	H' (±se)	*d* (±se)
Prunus spinosa	25	2.94 (±0.20)	5.99 (±0.88)	12	2.02 (±0.06)	4.03 (±0.44)
Crataegus monogyna	20	2.64 (±0.20)	5.20 (±1.00)	10	1.54 (±0.24)	3.22 (±0.46)
Populus spp.	17	2.62 (±0.38)	3.58 (±1.30)	9	1.88 (±0.38)	3.63 (± 0.06)
Euonymus europaeus	22	3.02 (±0.33)	8.46 (±2.20)	11	1.96 (±0.19)	4.55 (±0.17)
Cornus sanguinea	23	2.67 (±0.16)	4.53 (±0.75)	12	1.90 (±0.08)	3.09 (± 0.48)
Salix alba	12	2.14 (±0.57)	1.56 (±1.21)	6	1.46 (±0.28)	1.24 (±0.43)
Corylus avellana	22	2.82 (±0.44)	3.44 (±1.21)	10	1.52 (±0.27)	2.31 (±0.58)
Pyrus sp.	15	2.06	3.03	9	1.70	2.56

and VIS is shown in Tables 5 and 6, respectively. The number of species sampled by MKD was higher than those sampled by VIS. For some plant species (i.e. *E. europaeus* and *C. sanguinea*) the difference was very pronounced. VIS demonstrated to be particularly useful to study the phenology and the cycle of beneficials, but in our research this sampling technique showed a lower precision in comparison to MKD for the evaluation of species diversity.

Table 5. Comparison of coccinellid species sampled in 1997 with mechanical knock down (MKD) and visual inspection (VIS) on trees and shrubs of hedgerows.

	Prunus spinosa		*Populus alba*		*Crataegus monogyna*		*Corylus avellana*		*Euonymus europaeus*		*Cornus sanguinea*	
	MKD	VIS	MKD	VIS	MKD	VIS	MKD	VIS	*MKD*	VIS	MKD	VIS
Coccinella 7-punctata	●	●	●	●	●	●	●	●	●	●	●	●
Hippodamia variegata	●	●	●	●	●	●	●	●	●	●	●	●
Propylaea 14-punctata	●	●	●	●	●		●	●	●	●	●	●
Adalia 2-punctata	●	●	●	●	●	●	●	●	●	●	●	●
Synharmonia conglobata	●	●	●	●	●	●	●	●	●		●	●
Stethorus punctillum	●	●	●	●	●		●	●	●		●	●
Scymnus apetzi	●		●				●		●		●	
Scymnus rubromaculatus	●	●	●		●		●	●	●		●	●
Scymnus frontalis					●		●		●		●	
Scymnus interruptus											●	
Pullus (*Scymnus*) *auritus*	●			●	●		●		●		●	
Pullus subvillosus	●	●	●	●	●	●			●		●	
Coccidula rufa	●				●							
Lindorus lophantae							●	●	●		●	
Thea (*Psyllobora*) *22-punctata*							●	●	●		●	●
Chilocorus 2-pustulatus	●					●						
Total of species sampled	12	8	9	8	11	6	12	9	13	4	14	8

Table 6. Relative abundance (%) of coccinellids sampled by visual inspections (VIS) on weeds.
Weeds: DC = *Daucus carota*; RU = *Rumex* sp.; CI = *Cirsium* sp.; AR = *Arctium* sp.; AM = *Amaranthus retroflexus*; DI = *Dipsacus sylvestris*; CO = *Conyza canadensis*; CR = *Crepis* sp.; PI = *Picris* sp.; UD = *Urtica dioica*.

Coccinellid species	Weeds									
	DC	RU	CI	AR	AM	DI	CO	CR	PI	UD
Coccinella 7-punctata	0.2	20.7	52.5	0	0	0	0	0	0	8.8
Hippodamia variegata	99.8	61.3	25	81.2	100	100	100	100	100	62.4
Propylaea 14-punctata	0	10.9	10	12.5	0	0	0	0	0	8.0
Adalia 2-punctata	0	0	0	0	0	0	0	0	0	4.8
Synharmonia conglobata	0	0	0	0	0	0	0	0	0	0.4
Scymnus sp.	0	3.7	2.5	0	0	0	0	0	0	0
Scymnus apetzi	0	1.1	0	0	0	0	0	0	0	1.5
Pullus (Scymnus) auritus	0	0	0	0	0	0	0	0	0	4.2
Scymnus interruptus	0	0	0	0	0	0	0	0	0	2.16
Scymnus rubromaculatus	0	0.7	0	0	0	0	0	0	0	7.2
Pullus subvillosus	0	0	0	0	0	0	0	0	0	0.5
Scymnus frontalis	0	0.4	0	0	0	0	0	0	0	0
Chilocorus 2-pustulatus	0	0.4	0	0	0	0	0	0	0	0
Lindorus lophantae	0	0	0	6.25	0	0	0	0	0	0
Platynaspis luteorubra	0	0.7	0	0	0	0	0	0	0	0
Thea (*Psyllobora*) *22-punctata*	0	0	10	0	0	0	0	0	0	0

Table 7 provides information about the stages of predators found on the sampled plants, including weeds. Eggs and/or larvae of Coccinellidae were found on all the tree and shrub species, with the exception of *S. nigra*, thus demonstrating that hedgerows can supply multiplication sites for ladybirds. An example of the role of trees and shrubs in supplying prey food for coccinellids is shown in Figures 1 and 2. In some cases *P. spinosa* demonstrated to supply multiplication sites also for hoverflies (Figure 3).

VIS demonstrated also that trees and shrubs could supply a shelter for adult ladybirds mainly in late summer, a period in which many crops in our region are harvested. Evidence of this role as refugium is shown by the presence of adult stages of coccinellids without the presence of aphids (Figures 4 and 5). The aphid species infesting trees and shrubs in northern Italy were described by Nicoli *et al*. 1995 and Boriani *et al*. 1998.

A total of seventeen ladybird species were collected on shrubs and trees of hedgerows (Table 5). Aphidophagous species were the predominant group and the commonest species on trees and shrubs was *Adalia bipunctata* (L.), followed by other species belonging to the tribe of Coccinellini, as *Hippodamia variegata* (Goeze), *Propylaea quatuordecimpunctata* (L.), *Coccinella septempunctata* (L.), and seven species belonging to the tribe of Scymini. *Oenopia* (= *Synharmonia*) *conglobata* (L.) was less abundant in comparison to the previously mentioned species. *Coccidula rufa* (Herbst) (tribe of Coccidulini), a species that feeds mainly on aphids (Majerus, 1994), was rare and was sampled by means of MKD only on *P. spinosa* and *C. monogyna* at one site. Other species sampled were *Chilocorus bipustulatus* (L.), *Exochomus quadripustulatus* (L.) (Chilocorini), *Stethorus punctillum* (Weise) (Stethorini), and *Lindorus* (= *Rhizobius*) *lophantae* (Blaisdell) (Coccidulini). Also *Thea* (= *Psyllobora*) *vigintiduopunctata* (L.) (Psylloborini) was found, which is a mildew-feeding species (Majerus, 1994).

Table 7. Summary of the presence of the most abundant predator groups on trees, shrubs and weeds sampled by visual inspection (VIS) in 1995 and 1997. E = eggs; L = larvae; P = pupae or nymphs; A = adults

Plant Species	Coccinellidae			Syrphidae		Chrysopidae			Miridae		Nabidae		Anthocoridae	
	E	L-P	A	E	L-P	E	L-P	A	L-P	A	L-P	A	L-P	A
Prunus spinosa	+	+	+	+	+	+	+	+						
Populus spp.	+	+	+	+	+	+	+	+						
Crataegus monogyna	+	+	+	+	+	+	+	+					+	
Corylus avellana	+	+	+		+	+	+	+						
Salix alba	+	+	+	+	+	+	+	+					+	
Cornus sanguinea		+	+			+	+	+						
Euonymus europaeus		+	+	+	+	+	+	+						
Ulmus minor	+		+	+		+	+	+						
Sambucus nigra			+	+	+	+	+	+						
Cirsium arvense		+	+			+	+	+				+		+
Rumex spp.		+	+			+		+				+		
Urtica dioica	+	+	+			+	+	+	+	+		+	+	+
Daucus carota			+			+		+						
Dipsacus sylvestris		+	+		+									
Amaranthus retroflexus			+											
Conyza canadensis			+									+		+
Arctium spp.			+									+		
Crepis spp.		+	+	+										
Picris spp.			+											+

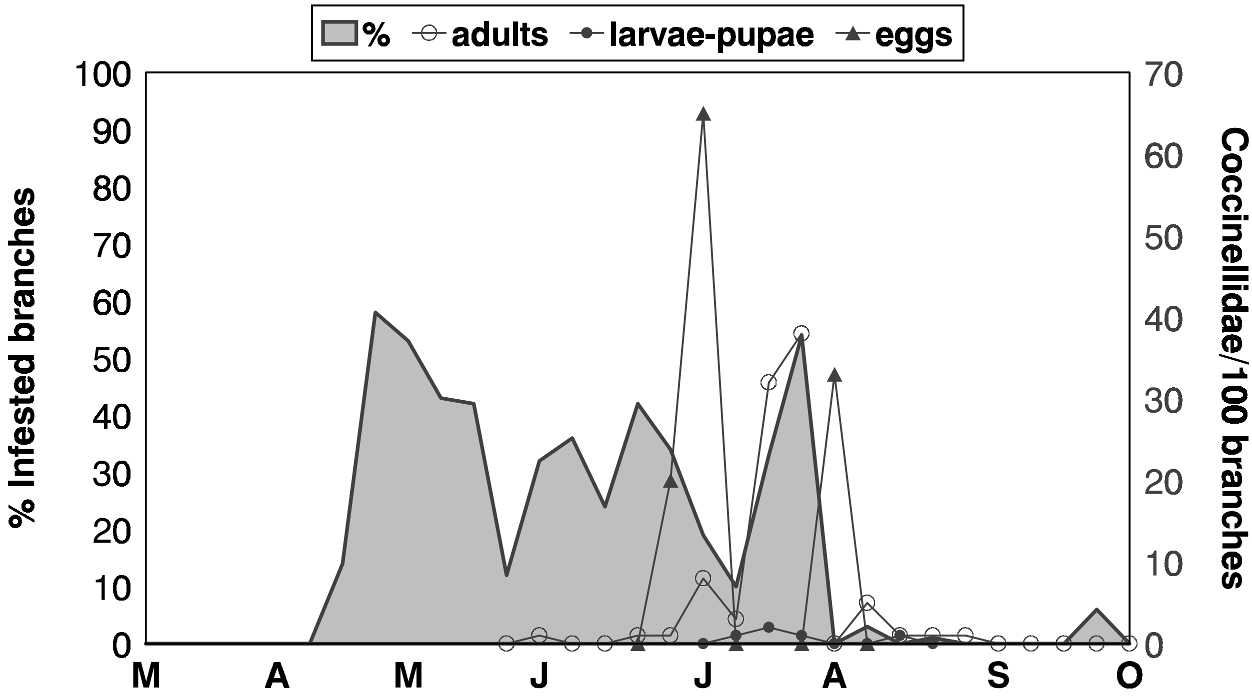

Figure 1. Number of coccinellids and percentageg of branches infested by aphids on *Populus* sp. over time.

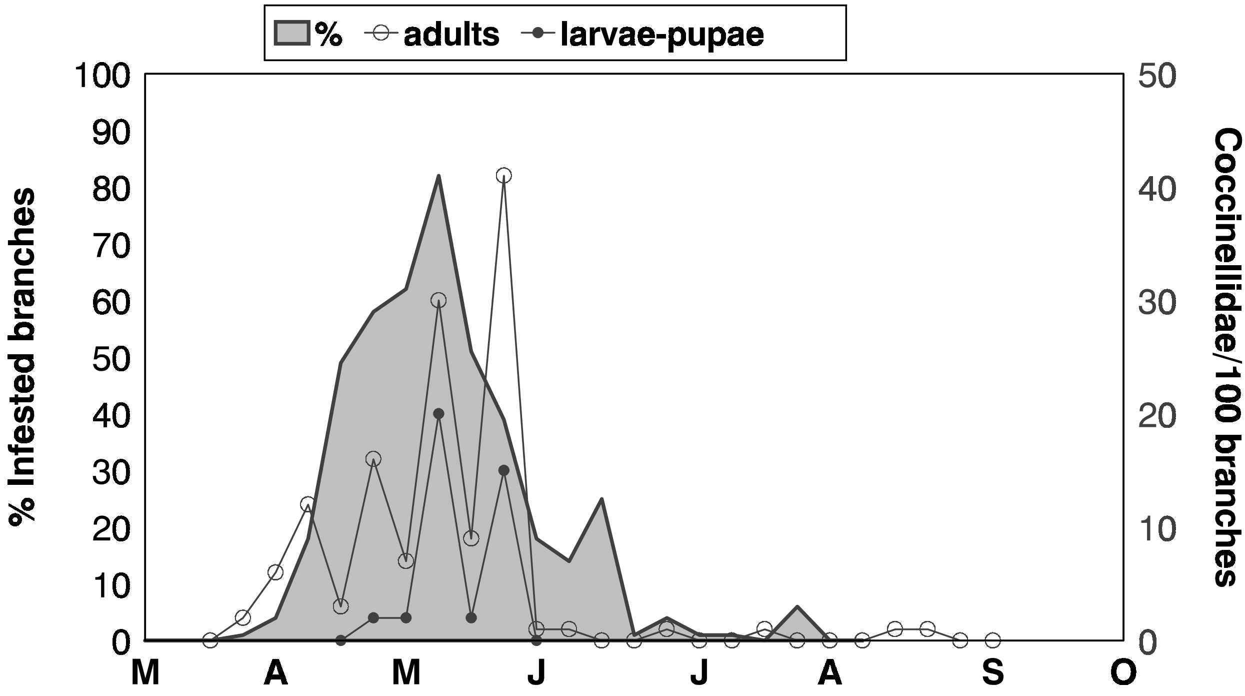

Figure 2. Number of coccinellids and percentage of branches infested by aphids on *Prunus spinosa* over time.

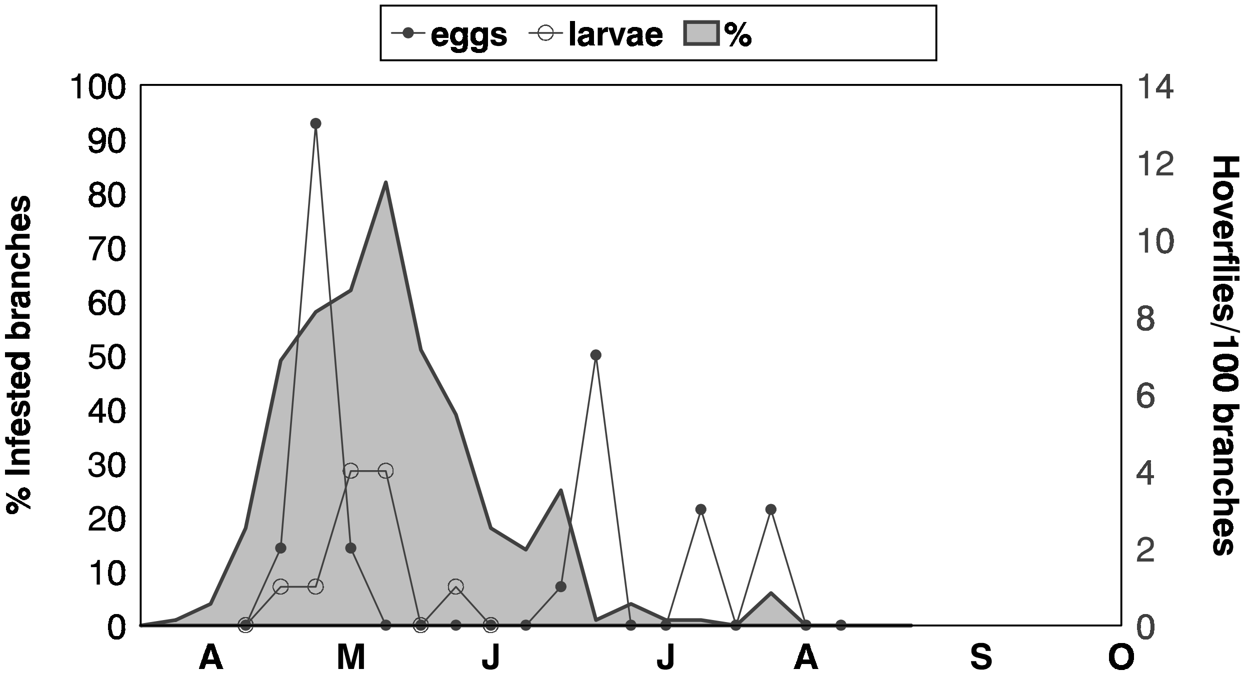

Figure 3. Number of Syrphid eggs and larvae, and percentage of branches infested by aphids on *Prunus spinosa* over time.

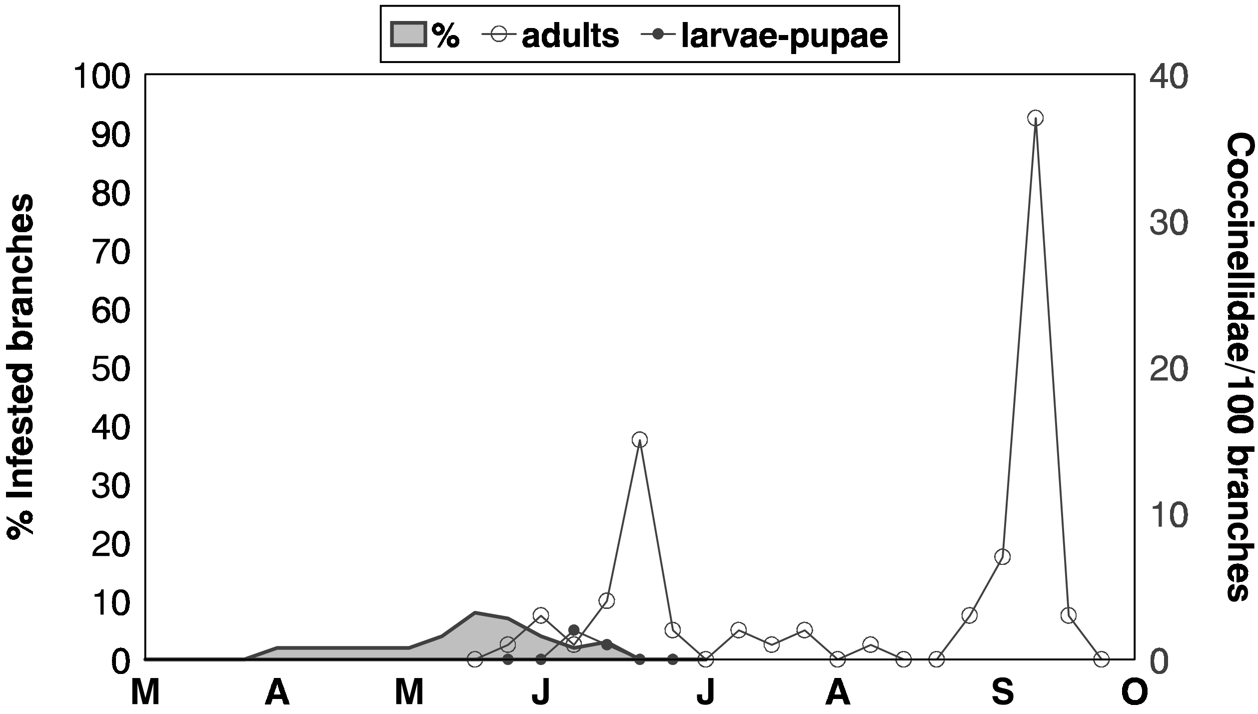

Figure 4. Number of coccinellids and percentage of branches infested by aphids on *Euonymus europaeus* over time.

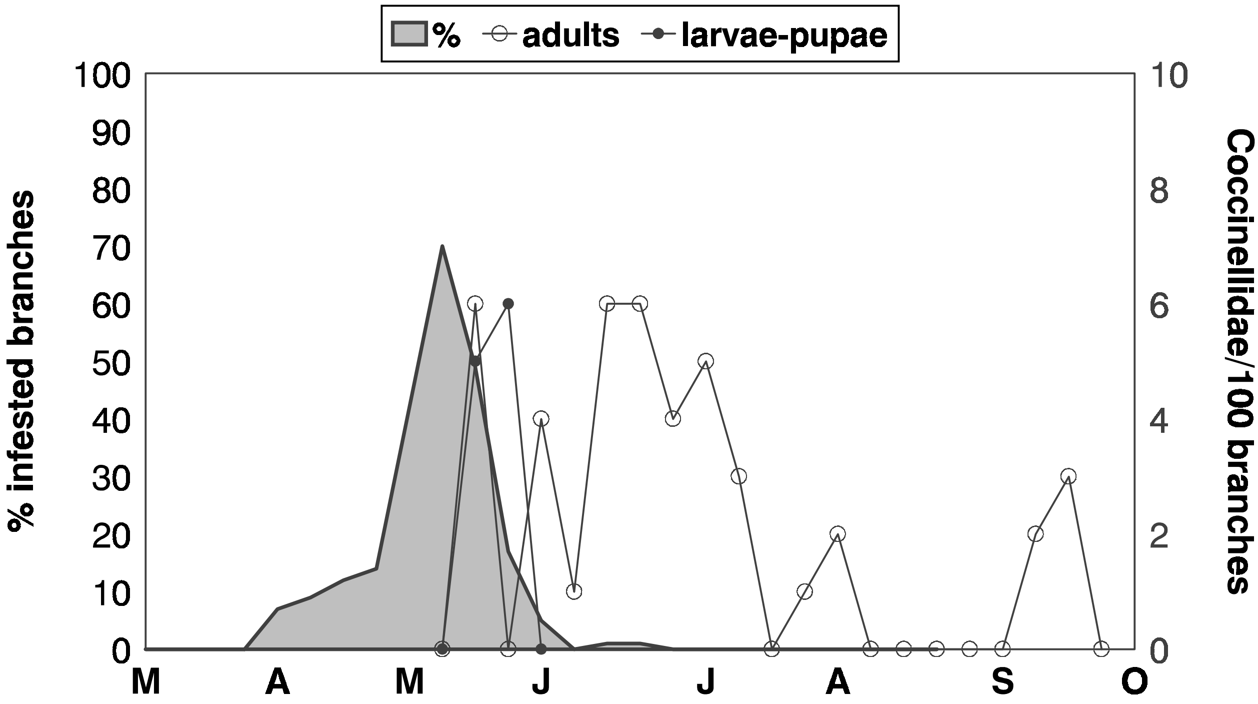

Figure 5. Coccinellids and percentage of branches infested by aphids on *Cornus sanguinea* over time.

Demetrias atricapillus (L.), a species common on trees, was the only carabid species collected. *Paederus* sp. was the only genus we found of the family of Staphylinidae. The species belonging to the family of Miridae were *Deraeocoris ruber* (L.), *Heterotoma meriopterum* Scopoli, *Pilophorus cinnamopterus* Kirschbaum. The only genera of Anthocoridae sampled were *Anthocoris* Fallén and *Orius* Wolff.

Also on weeds coccinellids were the dominant predators sampled. A list of ladybird species, including their relative abundance, is shown in Table 6. Among the weeds, *Cirsium* sp. (creeping thistle), *Rumex* sp. (dock) and *Urtica dioica* L. (stinging nettle) supported the multiplication of ladybirds (Table 7). Only adults of coccinellids were found on *Daucus carota* L., *Amaranthus retroflexus* L., *Dipsacus sylvestris* Hudson, *Arctium* sp., *Crepis* sp., *Picris* sp.. On *D. carota* adult density of *H. variegata* reached a peak between August and September, a period in which many crops are harvested in our region. Our data demonstrate that adults of ladybirds took shelter inside the flowers of *D. carota*. Moreover, *H. variegata* adults were observed feeding on pollen of *D. carota*. Pollen form secondary food for many aphidophagous species (e.g. Majerus, 1994; Triltsch,1999).

Table 7 shows that a group of ten plant species, including trees, shrubs and weeds, provided multiplication sites for Syrphidae, while thirteen plant species supported multiplication of Neuroptera Chrysopidae.

In Figure 6 I present a plot of plant and coccinellid species against the first two axes found by applying a correspondence analysis to the data (see material and methods). The matrix was created by all the data collected by VIS. Ordination by correspondence analysis involves using the plant and coccinellid values for the first few largest eigenvalues that are less than 1, because these are the solutions for which the correlations between rows and columns are strongest (Manly, 1994). Correspondence analysis gives an ordination of both

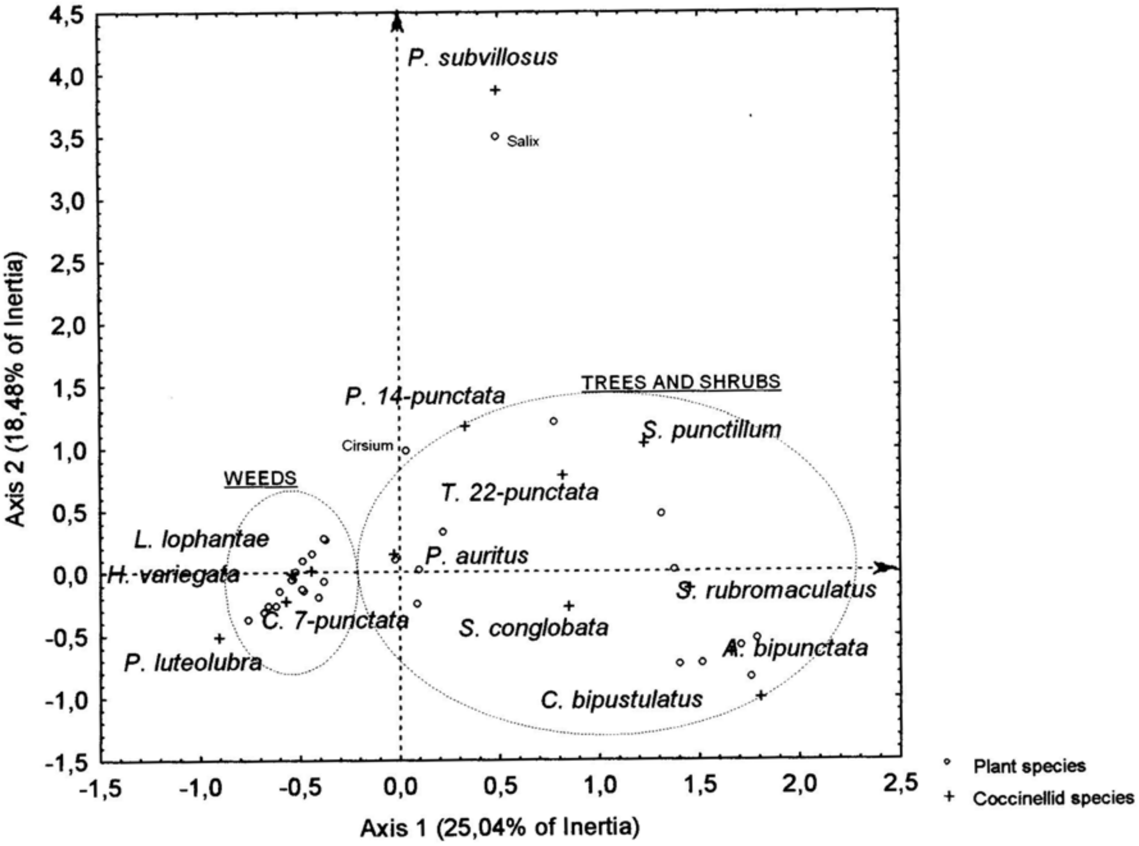

Figure 6. Ordination of the plant species on the basis of the abundance of coccinellid species recorded by visual inspection, by correspondence analysis; data analysed by a matrix *p* x *n*, where *p* are coccinellid species and *n* are plant species (*10* x *36* matrix).

plant and coccinellid species at the same time. The arch or "horseshoe" that appears in the ordination is a common feature for results obtained by a correspondence analysis (Manly, 1994). Coccinellid species that are typical of trees and shrubs [*A. bipunctata, S. conglobata*, *Scymnus rubromaculatus* (Goeze), *C. bipustulatus*] are clustered in the same group, and all these species were absent on weeds. Also *Pullus auritus* Thunberg, *L. lophantae, T. vigintiduopunctata* and *S. punctillum* were sampled only on trees and shrubs, but they were less abundant and their presence was not consistent. *H. variegata*, *C. septempunctata*, *P. quatuordecimpunctata* were found both on trees and weeds, with a different pattern. *H. variegata* was the dominant species on weeds and the only coccinellid species found on *D. carota*, *A. retroflexus*, *D. sylvestris*, *Conyza canadensis* (L.) Cronquist*, Crepis* sp., *Picris* sp.. *H. variegata* also colonised trees and shrubs. In general *H. variegata* was the most abundant coccinellid sampled in our study. *Platynaspis luteorubra* Goeze was rare and it was recorded only on *Rumex*. *Pullus subvillosus* (Goeze) was recorded only on *Salix* (see Figure 6 for the correspondence between plant and coccinellids). *C. septempunctata* was present on *Cirsium* and *Rumex*, but it was absent on the other weeds. This species was recorded by VIS also on trees and shrubs, but with high variability. *P. luteorubra* was recorded on *Rumex* and *L. lophantae* only on hazel. In general coccinellids showed some variability in the relative abundance among the plant species sampled at the different sites, probably reflecting local differences due to the microclimate, prey composition and physical environment.

In our study, the relative abundance of *A. bipunctata* on *U. dioica* was very low (4.8%). However, this coccinellid species was found on nine weed species and was the dominant species on trees and shrubs, confirming data of Nedved (1999).

The importance of Coccinellidae in conservation biological control is, among others, pointed out by Hodek and Honek (1996) and Iperti (1999). Hodek *et al*. (1966) described the coccinellid species that he found on *Euonymus* and considered the importance of increasing the population level of these predators by judicious management of weeds, trees and shrubs. In Hodek *et al.*'s (1966) study, *C. septempunctata* and *A. bipunctata* were the most abundant coccinellid species and *Adalia decempunctata* (L.) and *P. quatuordecimpunctata* were rare. Stechmannn (in Hodek and Honek, 1996) studied the coccinellid fauna of some shrubs and trees (*Crataegus* sp., *Rosa* sp. and *Prunus* sp.) in Germany. Three species, *Calvia quatuordecimpunctata* (L.), *A. bipunctata* and *A. decempunctata* were present both as larvae and adults, whereas only the adult of *Anatis ocellata* (L.), *C. septempunctata* and *P. quatordecimpunctata* were found. Bode (in Hodek and Honek, 1996) studied coccinellid communities on *Prunus padus* L. in spring. *A. bipunctata*, *C. septempunctata* and *P. quatuordecimpunctata* were dominant, but only the former species produced larvae on *P. padus*. Honek (1985) studied the habitat preferences of aphidophagous coccinellids in Central Bohemia and Southwest Slovakia, reporting the mean abundance of seven species on different host plants, including trees and shrubs typical of hedgerows. Honek's (1985) study revealed that the habitat diversification shown by adults of these species may be explained in terms of different preferences for three environmental factors: aphid abundance, insolation and type of plant cover. The species composition and abundance of adult Coccinellidae and Chrysopidae were investigated by Honek (1981) on some weed/aphid systems. Trophic and microclimatic requirements of adults and geographic and temporal distribution of populations were considered important factors affecting the composition of aphidophagous species complex. Nedved (1999) recorded twenty-one predatory species of ladybirds collected from a range of habitats in Central Bohemia and provided a list of aphid/plant host complexes on which the development stages were found. Leather *et al*. (1999) presented data on the distribution and abundance of ladybirds in non–crop habitats. Coccinellid abundance appeared to be most strongly correlated with the percentage ground cover of *Cirsium* sp., grasses and *U. dioica*. Leather *et al*. (1999) frequently found larvae and pupae of *C. septempunctata* and *A. bipunctata* on *Rubus* and *U. dioica*, and Honek (1981) found a high relative abundance of *A. bipunctata* on *U. dioica*.

Other studies have pointed out that ladybird population size is correlated with plant density, landscape and time of the year (e.g. Evans and Youssef, 1992).

Paoletti and Lorenzoni (1989) identified impacts of hedgerows on invertebrate dynamics, and concluded that:

i) during spring and autumn the hedgerows can support several specialized predators of *Tetranychus urticae* Koch, such as *Oligota flavicornis* Boisduval and Lacordaire, and *Stethorus punctillum* Weise, which in summer reduced spider mites moving into corn fields or soybean fields;

ii) polyphagous predators like spiders, carabids, staphylinids, syrphids and ants are also affected by the vicinity of hedgerows; and

iii) migration of a few predators such as *Orius majusculus* Reut. in the fields is more effective in the vicinity of hedgerows, and some predators such as Phytoseidae mites are at times more abundant near hedgerows.

Inter-relationships between pear and hedgerow tree species were studied by Rieux *et al.* (1999). Ash tree (*Fraxinus angustifolia* Vahl.) and ivy (*Hedera helix* L.) displayed a diversified fauna that was correlated with the pear tree community. Their influence on the pear tree fauna was different. Ash trees was inhabited by host specific psyllids and gall midges, which provided food for beneficial pear arthropods. Ivy acted as a refuge species for beneficial pear arthropods. Groppali *et al.* (1995) described the spider community of hedgerows located in northern Italy and provided biological and phenological data about some spider species. Pantaleoni (1982) and Pantaleoni and Sproccati (1988) studied the composition of the Neuroptera fauna related to herbs, shrubs and conifers in northern Italy.

Several authors have stressed that reintroducing a mosaic structure into the agricultural landscape composed of woodlots, hedgerows and wetlands can lead to the creation of multiple habitats for reproduction, feeding and sheltering of a number of beneficial arthropod species (e.g. Paoletti and Lorenzoni, 1989; van Emden, 1990; Andow, 1991; Delucchi, 1997; Altieri, 1999). Studies on habitat manipulation within agricultural landscapes, such as "island" habitats in cereal crops, have concentrated on polyphagous predators like carabid beetles, spiders (Thomas *et al.*, 1992; Kromp and Steinberger, 1992; Lys and Nentwig, 1994) and hoverflies (Lövei *et al.*, 1993; Hickman and Wratten, 1996; Frank, 1999). Leather *et al.* (1999) suggested that only a slight modification of the various proposed island habitats would be required to increase coccinellid populations in crop ecosystems, and that habitat preferences of coccinellids, which are more abundant in grasslands and field margins, may be related to the fact that these habitats are more exposed to the sun than wooded habitats.

Vegetational biodiversity in ECAs on or near farms can be considerable. In northern Italy 255 plant species belonging to 53 different families were recorded in a non-crop area of about 9 hectares on a farm in the rural landscape (Mongardi, 1999). These data show that a judicious management of a natural vegetation area on a farm can allow the conservation of a large amount of plant diversity, comparable to that of semi-natural landscapes.

In conclusion, our data demonstrated that *P. spinosa*, *Populus* spp., *C. monogyna*, *C. avellana*, *S. alba*, *C. sanguinea*, *E. europaeus*, *Ulmus minor* Miller (elm), among the trees and shrubs, and *C. arvense*, *Rumex* spp., *U. dioica*, *D. sylvestris*, *Crepis* spp., among the weeds, supported reproduction of ladybird populations. Furthermore, some trees, shrubs (i.e. *P. spinosa, C. monogyna* and *E. europaeus*) and weeds species (*D. sylvestris*, *D. carota*, *C. canadensis*, *A. retroflexus*, *Crepis* spp., *Picris* spp.) can supply shelter for adult ladybirds when aphids and/or crops are not present. Some weeds, like *D. carota*, supplied a feeding-site for *H. variegata*, providing pollen and refuges to coccinellids in late summer, a period in which many crops are harvested in northern Italy. The knowledge of the cycle and phenology of coccinellids is crucial to manage ECAs, and in particular to preserve coccinellid populations during cultural practices like grass cutting in agroecosystems. Realizing the importance of coccinellids in aphid control in northern Italy, low impact cutting techniques like strip harvesting of crops and natural vegetation should be considered (e.g. Iperti, 1999).

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Chapter 3

The effect of ecological infrastructures on Coccinellidae (Coleoptera) and other predators in weedy field margins within northern Italian agroecosystems

Abstract

The insect predator complex in weedy margins adjacent to crops was studied in order to understand the ecological role of non crop-habitats on generalist predators in a northern Italian rural landscape. Weedy field margins at ten sites of different age and maturity which were adjacent to hedgerows, were sampled wit a sweep net. Coleoptera (Coccinellidae) and Rhynchota (Nabidae) were the most abundant groups sampled in these weedy margins. *Hippodamia variegata* was the most abundant coccinellid species, followed by *Coccinella septempunctata* and *Propylaea quatuordecimpunctata.* Among the tribe of Scymnini, *Scymnus rubromaculatus* and *S. apetzi* were the most abundant species. A consistent population of *Anthocoris* sp. was recorded at one site only, and these Anthocorids probably originated from the adjacent pear orchard. The age and maturity of the hedgerows appear to influence the abundance and distribution of predator families in the adjacent weedy margins. Nabidae were the most abundant insects within margins adjacent to old hedgerows. These old hedgerows showed generally a more uniform distribution of relative predator abundance than younger hedgerows. The margins adjacent to young hedgerows were characterised by a strong predominance of Coccinellidae. Correspondence Analysis performed on predator abundance ordinated the sites according to the age of adjacent hedgerows and the intensity of ecological infrastructure management. Only one site, characterised by a dominance of Anthocorid predators, formed a separate group, and this was probably due to the influence of an adjacent pear orchard. The phenology of Coccinellidae was studied. These predators showed two developmental peaks: the first between June and July, and the second between September and October. Particularly the first peak showed large populations of coccinellid larvae in the weedy margins. The knowledge of the phenology of these beneficial predators results in a recommendation for the judicious management of ecological infrastructures in order to preserve and improve coccinellid and other predator populations.

Introduction

The maintenance and management of ecological infrastructures (= ecological compensation areas = ECAs) on rural farms is considered crucial in enhancing functional biodiversity for pest suppression (e.g. Boller et al., 2004). Recently these strategies have become a basic aspect for application of conservation biological control (e.g. Rossing et al., 2003). A number of studies and reviews have dealt with the effect of non-crop plants on popolations of beneficial insects (Pimentel, 1961; van Emden and Williams, 1974; Altieri and Letourneau,

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1982; Sheenan, 1986; Russell, 1989; Van Emden, 1990; Delucchi; 1997; Altieri, 1999; Andow, 1991; Paoletti, 1999; Landis et al., 2000; Altieri et al., 2003). Improving and managing ecological infrastructures, including weedy field margins, are considered an important aspect of sustainable agriculture because of their role in enhancing functional biodiversity and for their role in supporting movement of cyclic predators between crops and environment (Landis and Wratten, 2004; Winkler 2005).

In simplified agroecosystems, many ecological services associated with the maintenance or enhancement of biodiversity, such as biological control, are compromised (e.g. Altieri, 1999, Bukovinszky, 2004). The concept of restoring these functions by managing the ecological infrastructures of landscapes shows promise in alleviating problems linked to pest management (e.g. Landis and Wratten, 2004). Undisturbed habitats in or adjacent to crop fields can enhance the overwintering survival of natural enemies. In this context “grassy beetle banks” for the conservation of ground-dwelling arthropods have been adopted in several parts of Europe (Landis and Wratten, 2004). Overwintering predator populations exceeding 1100 individuals per square meter have been reported after two years of beetle bank establishment (Thomas et al., 1992).

Managing the non-crop habitat of a farm to improve conservation biological control requires a detailed basic knowledge of the trophic relationships among ecological non-crop plants, herbivores and beneficials. With this knowledge we may re-activate essential “ecological services” on a farm by rational management of ecological infrastructures, and in this way we may improve conservation biological control of pests. In Italy some studies have been carried out, but a “truly ecological perspective” has not yet been widely accepted and applied within pest management, probably because ecological knowledge on functional biodiversity seems to be very fragmented. Moreover, only a few trophic systems have been studied with the specific aim to improve conservation biological control (e.g. Paoletti and Lorenzoni, 1989). A review of agroecological models as applied in Italy, including some studies on field margins, has been compiled by Altieri et al. (2003).

The general aim of the research presented in this chapter was to study the insect predator complex in weedy margins adjacent to crops in order to understand the ecological role of non crop-habitats on generalist predators in a northern Italian rural landscape. Specific aims were: i) to compare the diversity of predator populations on weedy margins characterised by different maturity of the adjacent linear features (hedgerows); ii) to measure and quantify the predator diversity in these field margins, and iii) to study and understand the phenology of the predominant predators in order to able to develop practical recommendations for farmers to improve functional biodiversity and conservation biological control of economic pests.

Material and methods

Ten sites in the province of Bologna that are characterised by different age of linear features were investigated in 1997. Five site were characterised by old hedgerows, the others by young ones. We considered “old hedgerows” those linear features that have a minimum age of 50 years. The age of young hedgerows ranged form five to ten years. The main characteristics of the sites investigated, including the adjacent crops on the farm and the pest management strategies that were applied, are shown in Table 1. Sites in the Bologna province are characterised mainly by arable crops and, to a lesser extent, pear and apple orchards. The site “Cà il Rio” is a large farm involved in an European project of sustainable agriculture (Sarno,

Table 1. Characteristics of the sites that were sampled by sweep net and visual counts. ECA = ecological compensation areas. The category «intensity of ECA management» includes the following typologies: i) limited (weeds were cut only one time during the sampling period); ii) intensive (weeds cut about 4-5 times during the sampling period); iii) intermediate.

Sites	Farm	Locality	Adjacent crops	Pest management	Age of adjacent hedgerows	Intensity of ECA management	Most abundant trees and shrubs within hedgerows
1	Cà il Rio-1	Castel S. Pietro (Bo)	Arable	Advanced IPM	Old	Limited	*Morus nigra*, *Ulmus* spp., *Prunus spinosa*, *Robinia pseudoacacia*, *Populus* spp.,
2	Azzoguidi	Sala Bolognese (Bo)	Orchards	IPM	Old	Limited	*Prunus spinosa*, *Ulmus minor*, *Quercus* spp., *Sambucus nigra*, *Robinia pseudoacacia*, *Euonymus europeus, Cornus sanguinea*, *Fraxinus* spp., *Crataegus monogyna*
3	Maieutica-Bora	S. Giovanni in Persiceto (Bo)	Orchards	Organic	Old	Limited	*Crataegus monogyna*, *Ulmus* spp., *Prunus spinosa*, *Acer campestris*, *Sambucus nigra*, *Rosa canina*, *Cornus sanguinea*, *Populus* spp.
4	Gubellini	Bologna	Orchards	IPM	Old	Limited	*Salix alba*, *Sambucus nigra*, *Robinia psaudacacia*
5	Guazzaloca	Crevalcore (Bo)	Arable	IPM	Old	Limited	*Prunus spinosa*, *Populus* spp., *Fraxinus* spp., *Morus nigra*, *Ulmus* spp., *Acer campestre*
6	Breveglieri	Calderara di Reno (Bo)	Arable	IPM	Young	Intensive	*Populus* spp., *Corylus avellana*
7	Cà il Rio-2	Castel S. Pietro (Bo)	Arable	Advanced IPM	Young	Intermediate	*Euonymus europeus, Corylus avellana*, *Crataegus monogyna*, *Cornus sanguinea*
8	Cà il Rio-3	Castel S. Pietro (Bo)	Arable	Advanced IPM	Young	Intermediate	*Populus* spp., *Euonymus europeus, Crataegus monogyna*, *Cornus sanguinea*, *Pyrus pyraster*, *Corylus avellana*
9	Morisi	S. Giovanni in Persiceto (Bo)	Arable	Organic	Young	Intermediate	*Crataegus monogyna*, *Prunus spinosa*, *Cornus sanguinea, Corylus avellana*
10	Forni	S. Giovanni in Persiceto (Bo)	Arable	IPM	Young	Intensive	*Euonymus europeus*, *Crataegus monogyna*, *Prunus spinosa*, *Cornus sanguinea, Urtica dioica*, *Cirsium* spp., *Rumex* spp., *Dipsacus sylvestris, Picris* spp., *Crepis* spp.

1995) and it included three sampling locations: site 1 (old hedgerow), 2 (young hedgerow) and 3 (young hedgerow).

At each site a weedy transect of about 100 meters adjacent to the linear structure on the farm was selected and sampled by sweep net. The investigated field margins formed a mixture of weeds with a predominance of the following species: *Urtica dioica* L., *Amaranthus retroflexus* L., *Rumex* sp., *Daucus carota* L., *Plantago lanceolata* L., *Dipsacus sylvestris* Hudson, *Arctium* sp., *Cirsium arvense* (L.), *Conyza canadensis* (L.), *Crepis* sp., *Inula viscosa* (L.), *Picris echioides* L.. The composition of the weeds was relatively constant at the different sites, with some variability due to local factors. The most abundant weeds were: *U. dioica, D. carota, C. arvense, C. canadensis*.

Weeds were sampled every 7-10 days from April to October. The sweep net was applied in a standard way, taking 100 sweeps at each sampling date in each weed transect. Generalist predators were collected in plastic boxes, taken to laboratory and identified. Visual samples were also made on the most abundant weeds at each site by counting the number of stems infested by aphids on a total of 100 randomly selected stems.

Statistical analysis

Correspondence analysis (CA) was used to ordinate the weedy field margins at each site on the basis of the abundance of predator families. CA was calculated on a matrix ***p*** x ***n***, where ***p*** are family insects ***n*** are the sites (Manly, 1994).

The formula of Tonkyn (1980) was applied in order to convert the number of coccinellids collected by sweep net to the number of insects caught per volume unit of vegetation (cubic meters).

Biodiversity was also analysed by classic indices, like the Shannon-Weaver, Eveness and Berger-Parker index (Magurran, 1988).

Results and discussion

The predator families that were found during sampling are listed in Table 2. After pooling the data collected from all sites, we may conclude that Coccinellidae (Coleoptera) form the most abundant family of predators (53,7%), followed by Nabidae (Rhynchota) (21.6%) and Anthocoridae (9.18%). Nabidae formed the most abundant family at sites characterised by weedy margins adjacent to old and mature hedgerows (sites 1-5). The lower density of Nabidae, in particular *Nabis* sp., in transects near young hedgerows might be the result of the intensive management of the weeds during the sampling period. Other abundant families near old hedgerows were Anthocoridae (16.48%) and Coccinellidae (25.75%). The weedy margins adjacent to young hedgerow (sites 6-10) were characterised by a predominance of Coccinellidae (84%). Families poorly represented at all sites were Carabidae, Staphylinidae, Chrysopidae and Syrphidae (Table 2), but poor representation apparently depended on the sampling techniques used. Sampling by sweep net is only able to collect terrestrial Carabidae and Staphylinidae present in the weed canopy, and not those on the soil. Sampling by sweep net underestimated also the Syrphidae larval population because most species within this family have nocturnal activity. Moreover, sweep net sampling is not considered the standard method to collect adult Syrphidae (Sommaggio, 1999).

Ordination of sites and predator groups was carried out by Correspondence Analysis (CA) (Figure 1) in order to understand the similarity among sites and to correlate the abundance of families to the different weed transects within each site. This ordination method can be used on data that can be presented as a two-way table of measures of abundance, with the rows corresponding to one type of classification (in our case the “predator family”) and the columns to a second type of classification (in our case the “farms”). The aim of this multivariate method is to give an ordination of both farms and insect family at the same time. By means of this analysis the sites were ordinated following the age and maturity of the adjacent hedgerows (Figure 1). All the weedy margins close to young hedgerows were clustered in one group and were highly correlated with coccinellid populations. All these sites were almost overlapping, indicating a very low between-site variability (Figure 1). Four out of five sites characterised by old hedgerows clustered in one group and they were highly correlated with Chrysopidae, Staphilynidae, Nabidae, Syrphidae, Carabidae. Site 4 was an

Table 2. Overview of families of predators that were sampled. The numbers indicate the total of specimens collected.

Sites	Anthocoridae	Nabidae	Carabidae	Staphylinidae	Coccinellidae	Chrisopidae	Syrphidae
1	26	234	22	27	167	37	44
2	31	141	6	26	70	12	54
3	13	256	40	36	95	22	51
4	310	97	5	15	133	23	13
5	34	200	53	33	183	47	36
Total	414	928	126	137	648	141	198
%	15.97	35.80	4.86	5.29	25.0	5.44	7.64
6	6	48	0	2	646	4	9
7	7	20	1	1	637	8	23
8	0	35	0	3	255	7	13
9	7	76	1	9	163	12	17
10	0	44	3	1	410	9	15
Total	20	223	5	16	2111	40	77
%	0.80	8.95	0.20	0.64	84.71	1.61	3.09
Pooled	434	1151	131	153	2759	181	275
%	8.54	22.64	2.58	3.01	54.27	3.56	5.41

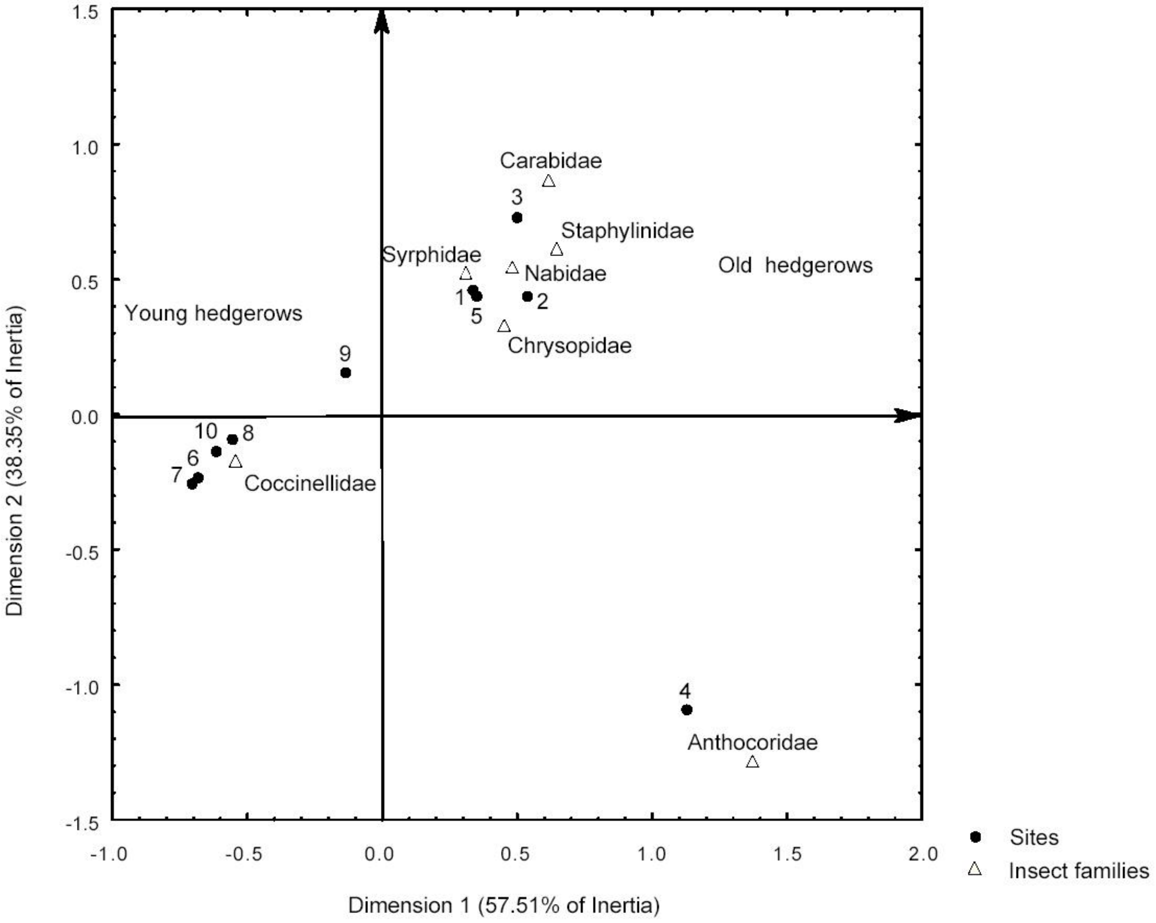

Figure 1. Correspondence analysis performed on the relative abundance of predator families on each farm.

exception and formed a separate group from all the other sites adjacent to old hedgerows. This farm had a very different predator guild with a predominance of Anthocoridae (*Anthocoris nemoralis*) populations, probably due to the adjacent pear orchard. For sites 1-5 (old hedgerows) the values of the Shannon-Weaver indices were higher in comparison with the Shannon indices found for sites 6-10 (young hedgerows). Also, eveness was in general higher in sites 1-5 in comparison to sites 6-10 (Table 3).

Carabidae and Staphylinidae showed differences in abundance at the different sites: relative abundances of these families were from 4.35 to 5.45% in margins adjacent to old hedgerows. Abundance values were under 1% recorded in margins adjacent to young hedgerows. The highest abundance of Carabidae and Staphylinidae in margins near the oldest hedgerows are expected to be the result of an overall higher biological diversity of the old and mature hedgerows.

Weed margins close to young hedgerows showed a stronger dominance in the population structure of the predator species. Contrarily, margins adjacent to old hedgerows showed a higher uniformity of relative abundances of predator families. The weeds adjacent to old hedgerows were managed with limited intensity during the sampling period (see Table 1). We suppose that the intensity of ECA management has affected the dominance of population structure of the weed margins and could be responsible for some of the differences in the composition of predatory guilds between the old and the young hedgerows.

Coccinellidae formed the most abundant family in “young margins” and one of the most abundant in the “old margins”. For this reason, and for their important role in conservation biological control in northern Italy, a temporal representation of the ladybird populations for these sites is shown (Figures 2-3). To better understand the phenology of coccinellid populations on weedy margins, the Coccinellidae populations were pooled and normalised to be able to show the trend of the percentage of presence of ladybirds during the season (Figure 4). Coccinellid populations show two main peaks, the first in early summer (from early June to early July) and a second one in late summer (from the end of August to the end of September). Among the plant species of the weedy field margins, *Cirsium, Rumex* and *Urtica* were most infested by aphids. Aphid populations showed a very strong variability in appearance and intensity among sites, and at some sites the aphid populations occurred in a very clustered way. For these reasons only a some data of aphid infestations on weeds are presented. Aphids on *Cirsium, Rumex* and *U. dioica* showed a more or less continuous

Table 3. Various biodiversity indices determined for the sampled sites. Site numbers are explained in Table 1.

Sites	Shannon (H)	Eveness	Berger-Parker (1/d)
1	2.25	0.75	2.70
2	2.16	0.73	2.75
3	2.23	0.75	2.97
4	2.1	0.69	2.63
5	2.65	0.84	5.72
6	1.30	0.48	2.26
7	1.13	0.42	1.40
8	1.63	0.68	2.63
9	2.10	0.76	2.64
10	1.56	0.59	2.25

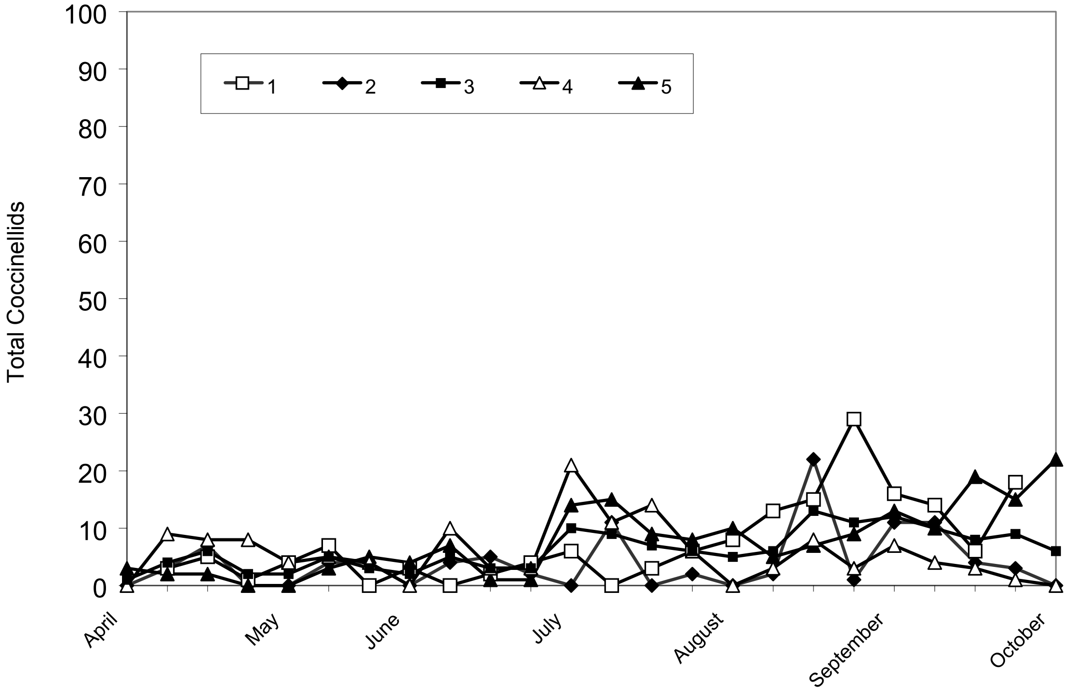

Figure 2. Numbers of coccinellids sampled on farms 1-5 (The numbers in the figure represent the sites as described in Table 1).

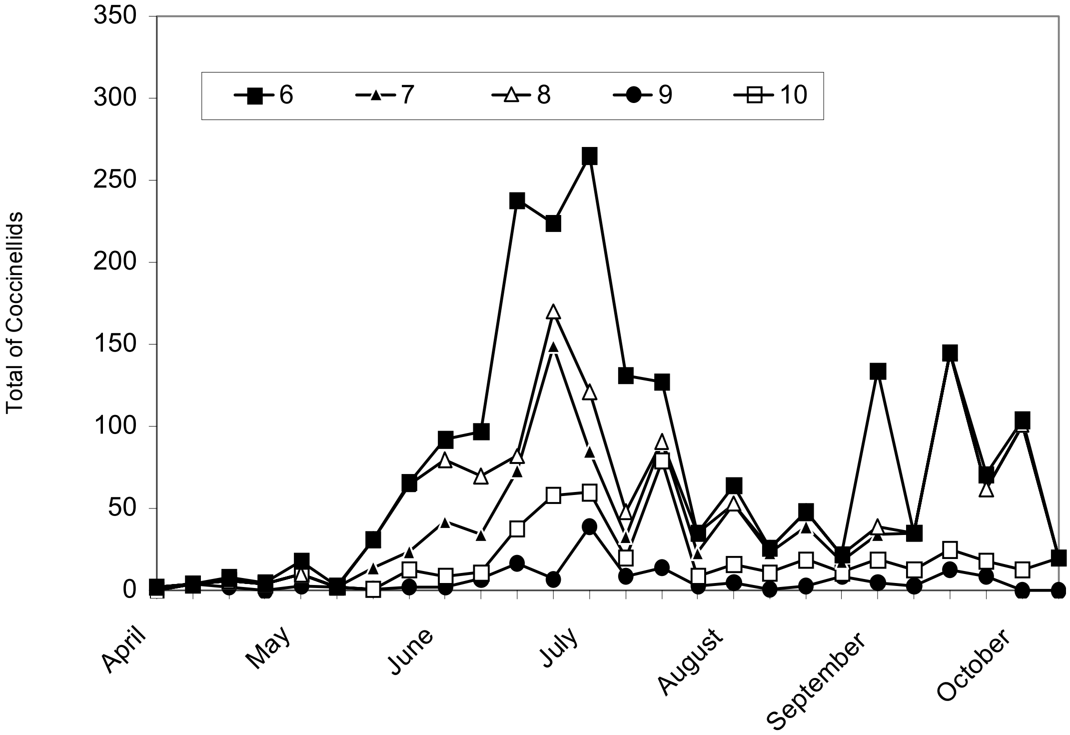

Figure 3. Numbers of coccinellids sampled on farms 6-10 (The numbers in the figure represent the sites as described in Table 1).

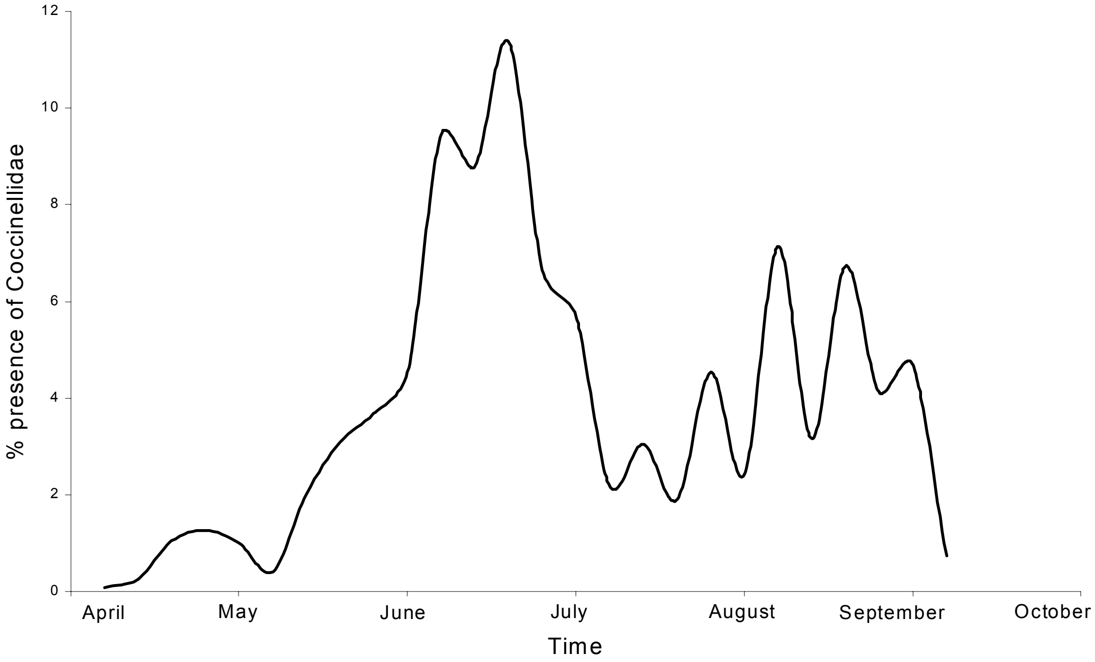

Figure 4. Coccinellid populations sampled in weedy margins represented as percentage of presence of the total population (data pooled over all years and sites).

presence throughout the season, with a peak infestation in May-June at some sites, and in July-August at other sites. The peaks of aphid infestation in summer occurred at the same time of the population peaks of coccinellids. The coccinellids showed an intense reproductive activity between June and July, illustrated by the presence of a mixed stage population with a massive presence of larvae and eggs. Contrarily, the peak in September–October was represented only by adult coccinellids. These data are similar to those presented in previous studies carried out in the same region (see chapter 2). This latter study demonstrated that *D. carota* and *A. retroflexus,* and to a lesser extent *D. sylvestris, Arctium* spp., *Crepis* spp., *Picris* spp., were the main weeds utilised by coccinellids as refuge resources in late season when the arable crops in northern Italy had been harvested.

Hippodamia variegata (Goeze) was the most abundant coccinellid species found in this research, followed by *Coccinella septempunctata* L., *Propylaea quatuordecimpunctata* (L.) and the *Scymnus* group (Tables 4-5). Among Scymnini, *Scymnus rubromaculatus* (Goeze) and *S. apetzi* Mulsant were the most abundant species. The formula of Tonkyn (1980) was applied in order to convert coccinellid populations collected by sweep net to the number of specimens caught per volume unit of vegetation (cubic meters) (Table 6). Considering the variability in structure and volume of weedy canopy along the seasons, the Tonkyn formula was applied for two fixed periods of the year, corresponding to the maximum canopy development (Table 6). Highest population densities of coccinellids were reached for site 6 at the beginning of July: 3.6 individuals per cubic meter. Coccinellid populations peaks ranged between values of 0.17 and 2.37 specimens per cubic meter during the second peak.

Table 4. Predator species sampled in weedy field margins adjacent to old hedgerows. The numbers indicate the total of specimens collected.

Insect species/genus	Family	Sites				
		1	2	3	4	5
Anthocoris sp.	Anthocoridae	-	25	4	225	7
Orius sp.		26	6	9	85	27
Nabis sp.	Nabidae	192	108	158	87	90
Aptus mirmicoides		21	22	61	5	58
undetermined Nabidae		21	11	37	5	52
Demetrias atricapillus	Carabidae	21	6	37	5	52
undetermined Carabidae		1	-	3	-	1
Tachyporus sp.	Staphylinidae	8	2	3	4	6
Paederus sp.		10	24	32	11	11
undetermined Staphylinidae		9	-	1	-	16
Coccinella septempunctata	Coccinellidae	29	-	-	-	3
Hippodamia variegata		57	7	43	6	27
Propylaea quatuordecimpunctata		48	32	29	49	54
Adalia bipunctata		-	3	8	14	31
Synarmonia conglobata		-	2	2	5	9
Stethorus punctillum		11	9	-	7	6
Scymnus sp.		19	9	11	47	26
Chilocorus bipustulatus		-	-	1	-	2
Thea vigintiduopunctata		3	7	1	5	25
Chrysoperla carnea	Chrysopidae	36	11	22	23	43
Chrysopa perla		-	-	-	-	3
Mallada sp.		1	1	-	-	1
Episyrphus balteatus	Syrphidae	8	10	8	4	10
Malanostoma mellinum		16	30	35	7	21
Sphaerophoria scripta		-	6	3	1	1
Syrphus sp.		1	2	-	-	1
Meliscaeva sp.		2	-	3	-	2
Eristalis arbustorum		5	-	-	-	-
Syritta sp.		2	-	-	-	-
Eumerus sogdianus		2	-	-	-	-
undetermined hoverfly larvae		8	6	2	1	1

Species within the Nabidae family, like *Aptus mirmicoides* (Costa), *Nabis punctatus* Costa and *N. rugosus* (L.) are polyphagous predators living in herbs and bushes. Other species like *Himacerus apterus* (F.), *N. ferus* (L.) and *N. pseudoferus* Remane are typical of apple and pear orchard and prey on mites, aphids caterpillars, and other small insects (Fauvel, 1999).

Among the Coleoptera Staphylinidae, some *Tachyporus* species are considered important in cereal aphid control, and a study carried out in barley fields in Denmark demonstrated that *Tachyporus* spp. are present in the crop from mid May onwards and prior to the appearance of aphids (Pedersen et al., 1990). In Sunderland and Vickerman's (1980) ranking of the most efficient predators, *Tachyporus* is one of the few predators that forages on the upper part of the tillers. In particular the ability of *Tachyporus* to disperse rapidly and thoroughly in cereals in early spring makes it a useful predator (Coombes and Sotherton, 1986). Faunistic notes on *Tachiporus* and other staphylinid genera in agricultural fields are reported by Andersen (1991).

Table 5. Predator species sampled in weedy field margins adjacent to young hedgerows. The numbers indicate the total of specimens collected.

Insect species/genus	Family	Sites 6	 7	 8	 9	 10
Orius sp.	Anthocoridae	6	7	-	7	-
Nabis sp.	Nabidae	47	20	33	52	43
Aptus mirmicoides		1	-	-	5	1
undetermined Nabidae		-	-	2	19	-
Demetrias atricapillus	Carabidae	-	1	-	1	3
Tachyporus sp.	Staphylinidae	1	1	-	1	1
Paederus sp.		1	-	3	8	-
Coccinella septempunctata	Coccinellidae	69	67	90	4	23
Hippodamia variegata		318	500	119	11	67
Propylaea quatuordecimpunctata		91	35	27	37	68
Adalia bipunctata		-	-	-	-	14
Synarmonia conglobata		1	2	-	4	-
Stethorus punctillum		4	1	-	-	8
Scymnus apetzi		39	8	5	24	73
Scymnus rubromaculatus		50	14	8	52	58
Scymnus frontalis		62	4	-	7	60
Scymnus interruptus		1	1	-	-	1
Pullus auritus		9	2	-	13	6
Pullus subvillosus		-	-	-	2	6
Platynaspis luteolubra		1	-	-	-	-
Coccidula rufa		-	1	-	-	-
Thea vigintiduopunctata		1	2	6	9	26
Chrysoperla carnea	Chrysopidae	4	7	6	6	6
Chrysopa perla		-	1	1	4	3
Malanostoma mellinum	Syrphidae	6	21	11	8	2
Sphaerophoria scripta		3	2	2	9	13

Table 6. Peaks of coccinellid numbers sampled as number of specimens per cubic meter. A volume of 0.4 cubic meters was estimated for each sweep net sample according to Tonkyn (1980).

Sites	Coccinellids per cubic meter First peak	 Second peak
1	0.15	0.72
2	0.22	0.27
3	0.27	0.55
4	0.52	0.17
5	0.37	0.47
6	3.60	2.37
7	2.27	2.20
8	0.90	0.22
9	0.97	0.32
10	1.17	0.32

A similar searching behaviour as that of *Tachyporus* is shown by the carabid *Demetrias atricapillus* (L.). This species is in Italy linked to field margins and grassy canopy characterised by high humidity and to mulches within crops (Vigna Taglianti, 2001; Drioli, 1978). *D. atricapillus* is typical of soils with *Phragmites* spp. and has a good dispersal capacity.

Data of the present research were critically analysed taking into account also the earlier studies performed in northern Italy on coccinellid dynamics in ecological compensation areas and crops (Nicoli et al., 1995; Molinari et al., 1998; Burgio et al., 2000; Cornale et al., 1996; Ferrari et al., 1996; Burgio et al., 1999; Burgio et al., 2004). I summarize the current hypothesis about the cyclic movement of coccinellids between arable crops, ecological compensation areas, fallow and open field vegetable crops in Figure 5. In agroecosystems of northern Italy, the period between late May and early July is crucial for the maintenance of predator populations because at that time many coccinellid species are in their reproductive period. Our data seem to demonstrate that in early summer coccinellid populations are migrating to and settling in weeds. These coccinellids originate mainly from wheat which is harvested in early summer (Burgio et al., 1999). Moreover, high coccinellid larval populations were recorded on weeds between May and July, thus demonstrating the role of field margins for recruiting and reproduction of these beneficials. In September-October, a second peak of coccinellid populations is registered on weeds, mainly represented by adults. Although we expect that in this period mowing might be less destructive for the beneficial fauna, weeds like *D. carota* and *A. retroflexus* (see chapter 2) still collect high populations of coccinellids that come from the last two alfalfa cuttings (Burgio et al., 1999). Further, during this part of the season arable crops are already harvested and weeds within ecological infrastructures become crucial for survival of these cyclic colonizers. Besides coccinellids, also young instars of other beneficial predators including Nabidae, Anthocoridae, Chrysopidae and Syrphidae were recorded on weeds in similar studies (e.g. Burgio et al., 2004; see also chapter 2), confirming literature data of Sommaggio (1999) and Boller et al. (2004) and providing new phenological data for agroecosystems of northern Italy.

Proper management of mowing, including timing, is recommended during the whole season in order to preserve and stimulate the development of insect predators, including coccinellid populations. Field margins play a crucial role in regulating the cycle of coccinellids and other predators, contributing to the cyclic movements from weeds to crop and *viceversa*. Mowing of weeds, wildflower strips and grassland strips in this period could be destructive for coccinellid populations, and the management procedures of field borders should take into account the phenology of beneficials. The negative impact of mowing techniques on faunistic diversity is treated by Boller et al. (2004). They provide a list of recommendations to augment faunistic diversity, including level, direction, period and frequency of mowing. For example, the first cut should be made as late as possible, and use a procedure that is least harmful to the fauna (Boller et al., 2004). This conclusion is in agreement with our results. Our data seem to demonstrate that in a multifunctional agriculture context, a judicious management of ecological infrastructures is crucial for conservation of beneficial fauna, thus contributing to the implementation of conservation biological control. Considering the local variability in the cycles of beneficial fauna, due to geographical, climatic, and environmental variation among regions and countries, recommendations on the maintenance and management of ecological infrastructures should be designed for the local scale and should consider the characteristics of each geographic area and the specific knowledge of each agroecosystem.

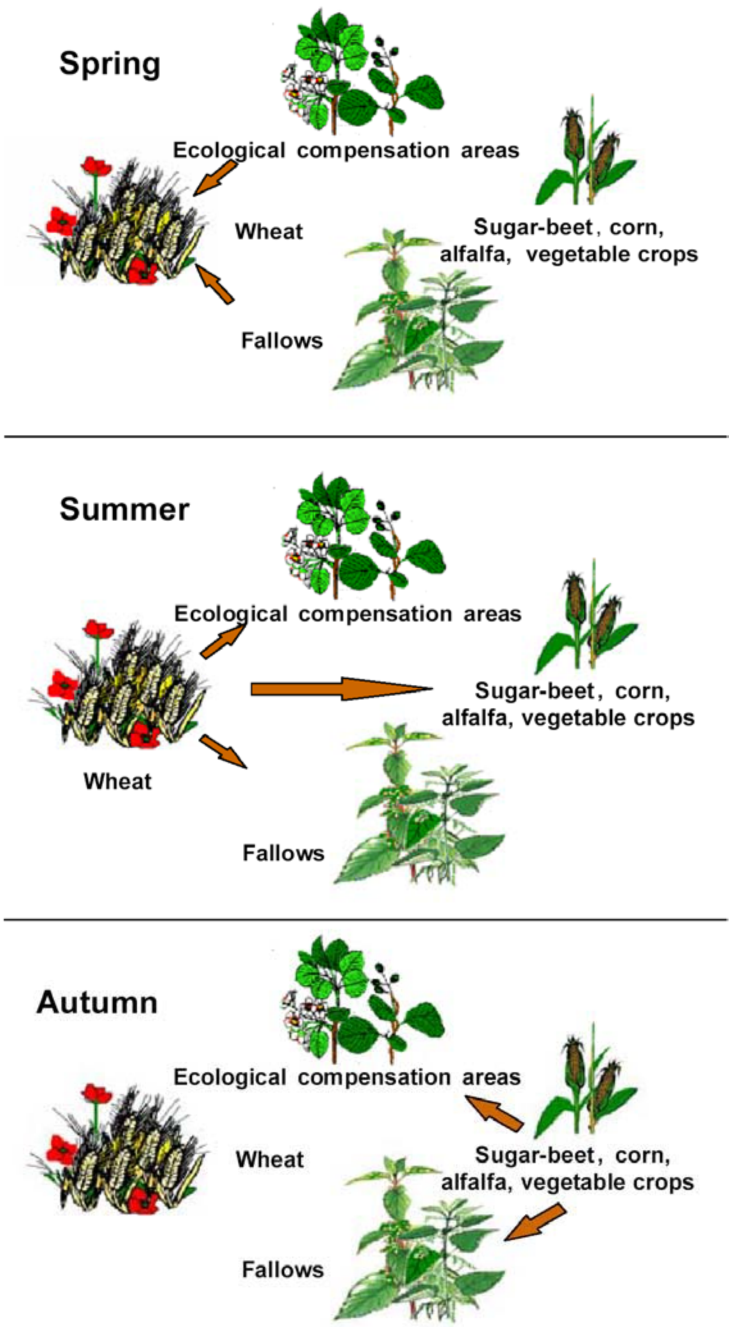

Figure 5. Diagram showing the cyclic colonisation of coccinellids between crops and non-crop areas. Drawing by Roberto Ferrari.

In conclusion, an abundant predator insect fauna was recorded on weeds in field margins, confirming the key role of ecological infrastructures within the rural landscape. A judicious management of ecological infrastructures is considered very important for the survival and augmentation of these cyclic colonizing predators. This study has improved the knowledge of the phenology of coccinellids in field margins in our region (see Fig. 4-5) and contributes to the development of better management strategies of ecological compensation areas.

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Section 2

Analysis of the role of non-crop plants on the conservation biological control of agromyzid pests

Chapter 4

Faunistic study of the Diptera Agromyzidae and related parasitoids on weeds of ecological compensation areas in northern Italian agroecosystems

Chapter 5

Spatial patterns and sampling plan for *Liriomyza huidobrensis* (Blanchard) (Diptera: Agromyzidae) and their parasitoids on lettuce

Chapter 6

Role of annual flowering plant mixture on parasitism of agromyzid leafminers (Diptera: Agromyzidae) on lettuce

Chapter 4

Faunistic study of Diptera Agromyzidae and their parasitoids on weeds in ecological compensation areas in northern Italian agroecosystems

Abstract

The role of weeds in field margins on agromyzids and their parasitoids was studied at rural farms with ecological compensation areas with different complexity and floral composition. Field samplings were carried out in 1998 and 1999, by weekly collecting foliage infested with leafminers from the representative weedy plants in three sites located in the province of Bologna, Italy. A total of 646 agromyzid specimens were reared, representing eight genera and 24 species. The most abundant species were *Chromatomyia horticola* (Goureau), *Phytomyza lappae* Goureau, *Phytomyza ranunculi* Schrank, *Phytomyza plantaginis* Robineau-Desvoidy, *Liriomyza trifolii* (Burgess) and *Ophiomyia pulicaria* (Meigen). *Chromatomyia horticola* was the dominant species accounting for 35.76 % of adults reared. Agromyzids mined 25 plant species belonging to nine families. The Asteraceae, in particular *Cirsium arvense* (L.) Scopoli and *Sonchus asper* (L.) Hill, were the most important sources of leafminers considering both species richness and population densities. Shannon-Weaver (H'), Simpson (D) and Berger-Parker (d) indices all pointed out that agromyzid species diversity was higher in the site characterised by the highest floral richness, the highest complexity of the ecological network, and a non-intensive type of agriculture. Concerning the Hymenoptera, 998 specimens, representing five families, 23 genera, and 53 species, were reared from leafminers infesting weeds. Eulophidae were the most abundant family (67.64%), followed by Braconidae (28.86%), Eucoilinae (1.40%), Tetracampidae (1.40%) and Pteromalidae (0.7 %). Braconids were the most species rich family accounting for 28 species, Eulophidae were represented by 19 species, Pteromalidae by four species, and Eucoilinae and Tetracampidae by one species each. The dominant parasitoid was the eulophid *Pedioubius metallicus* (Nees), representing 18.17% of the total, followed by *Diglyphus isaea* (Walker) (12.73%), and *Neochrysocharis formosa* (Westwood) (10.82%). The most abundant braconid parasitoid was *Dacnusa maculipes* Thomson (9.62). Over 80% of parasitoids were recovered from 10 plant species: *Cirsium arvense* (L.) Scopoli, *P. lanceolata*, *Sonchus asper* (L.) Hill, *Papaver rhoeas* L. *Picris echioides* L., *Lactuca serriola* L., *Myagrum perfoliatum* L., *Ranunculus velutinus* Tenore, *Arctium lappa* L., *Medicago sativa* L.. Based on our findings, we conclude that preservation and management of wild plants within field margins can be crucial tools to enhance populations of biological control agents of agromyzids and to conserve rare parasitic wasp species.

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Introduction

Agromyzid leafminers (Diptera: Agromyzidae) are among the most serious insect pests of vegetables and ornamental plants all over the world (Spencer, 1973). In Italy about 250 species are recorded (Canzoneri et al., 1995; Süss, 2003), but only the accidentally introduced *Liriomyza huidobrensis* (Blanchard) causes severe damage in open field vegetables. In many circumstances it is considered a secondary pest, because application of broad-spectrum insecticides reduces the number of leafminer natural enemies, thus resulting in pest outbreaks (Johnson et al., 1980). Since adulticides are poorly effective against this leafminer, because they negatively impact natural enemies and can rapidly select resistant strains within fly populations (Weintraub and Horowitz, 1995), biological control against these pests needs to be improved. In Italy empirical evidence demonstrated that suppression of insecticides on lettuce, combined with a rational management of field margin habitats, can result in an effective control of leafminers (Lanzoni et al., 2003).

Management of agromyzid leafminers has been extensively researched over the last 30 years and several studies have been made on the natural enemies of economic pests like *Liriomyza* spp. (Zoebisch and Schuster, 1987; Parkman et al., 1989; Schuster et al., 1991; Murphy and LaSalle, 1999). Hågvar et al. (1998) demonstrated that field boundaries are important for the control of *Chromatomyia fuscula* (Zetterstedt) (Diptera: Agromyzidae), a cereal pest in Scandinavia; in particular field boundaries that provide part of the parasitoids' foraging and overwintering area. These boundaries were more important to the parasitoids than to their leafminer host.

Although some predators have been observed attacking agromyzids (Parrella et al. 1982), hymenopteran parasitoids are considered the most effective natural enemies of these leafminers (Parrella, 1987). Most information comes from studies on parasitoids of polyphagous *Liriomyza* species in agricultural systems (e.g. Johnson and Hara, 1987), and only few surveys have been conducted on non-economically important leafminers feeding on weeds (Salvo and Valladares, 1999; Gratton and Welter, 2001). Parasitoid assemblages are dominated by Braconidae and Eulophidae, but also several species of Pteromalidae, Tetracampidae and Eucoilidae have been recorded (Murphy and LaSalle, 1999). Several surveys were conducted in Italy for natural enemies of leafminer pests in greenhouses (e.g. Del Bene, 1989), and only preliminary data from a single-year study are available for parasitoids recovered in field margins (Burgio et al., 2000).

In their review, Murphy and LaSalle (1999) pointed out that in many circumstances conserved biodiversity contains a pool of parasitoid species that could contribute to controlling agromyzid pests, and they concluded that more effort should be made to conserve and enhance local natural enemies rather than to release exotic parasitoids. Since conservation biological control relies on landscape management, greater knowledge of the tritrophic interactions among weeds-leafminers-parasitoids is fundamental. In this context, a judicious management of margins, hedgerows, fencerows, wetlands and woodlots could lead to the creation of various habitats for reproduction, feeding and shelter of a number of beneficial insects among which leafminer natural enemies (Schuster et al., 1991; Shepard et al., 1998; Rauf et al., 2000).

The aims of the research described in this paper were: i) to study the influence of weeds on populations of agromyzids and their parasitoids, in order to develop ideas for augmentation of populations of natural enemies; ii) to assess the influence of structural characteristics of Ecological Compensation Areas and the effect of pest management strategies on communities of agromyzids and their parasitoids.

Material and methods

Field samplings were conducted from April to October of 1998 and 1999 on three farms located in the province of Bologna (northern Italy, ≈45°N latitude). Sampling sites were established in non-crop areas of about 1000 m^2 nearby hedgerows, each of different age, composition, spatial structure, and connection with ecological corridors. The characteristics of each site are summarised in Table 1. Sampling areas ranged from a semi-natural ecosystem characterised by complex nets of ecological corridors where no control measures were applied (site 3), to an isolated agroecosystem managed by chemical control (site 2). The transect in site 1 was located near to a hedgerow in patches of shrubs with an average connectivity; in this case, pest management was carried out by an advanced IPM program.

In each site, a transect of 10 by 30 m was sampled weekly by the same two persons for a fixed time period of one hour. The representative weed species in each site were examined for the presence of mines. Leaves and stems infested by leafminers were removed, stored in ice bags and returned to the laboratory. Foliage was observed, using a dissecting microscope to eliminate any insects, if any, present on its surface. Moreover, the mines were observed by transmitted light and any leafminer not belonging to agromyzids was removed. In this way, the development of parasitoids not feeding on agromyzids was avoided.

Foliage, previously categorised by date, site of collection, and host plant species was stored in Plexiglas cylindrical cages (Ø 9 cm, h 9, 18 or 27 cm) to rear leafminers and parasitoids to adulthood. Plant samples were hung to a wire, and each container was closed with fine gauze to increase air circulation and to reduce mould growth. To keep even the smallest leaves turgid long enough for agromyzids to pupate and for parasitoids to complete their development, the petioles of several leaves were rolled together in cotton-wool, thus forming plugs that were inserted into water-filled vials. The vials were placed in cages as previously described.

Containers were stored in a climatic chamber at 25 ± 1 °C, 80 ± 10% RH, and LD 16:8 h photoperiod for 40 days. Once a week puparia, when pupation occurred outside the leaf, and adult wasps were removed form containers. Leafminer puparia were placed in glass vials plugged with cotton and stored in the climatic chamber to check the emergence of adult larval/pupal parasitoids. Individuals were killed and prepared for identification.

Most agromyzid specimens were identified to species by Luciano Süss (Istituto di Entomologia Agraria, Università di Milano, Italy). Braconidae were identified to species by

Table 1. Features of each hedgerow near sampled transects.

Hedgerow Features	Site 1	Site 2	Site 3
Age	5 Years	4 Years	6 Years
Main Arboreal Plants	*Cornus sanguinea* L. *Corylus avellana* L. *Crataegus monogyna* L. *Evonymus europaeus* L. *Populus* spp. *Pyrus pyraster* Burgsd.	*Cornus sanguinea* L. *Crataegus monogyna* L. *Evonymus europaeus* L. *Prunus domestica* L.	*Cornus sanguinea* L. *Corylus avellana* L. *Crataegus monogyna* L. *Evonymus europaeus* L. *Prunus domestica* L. *Salix* spp.
Connectivity	Average	Isolated	High
Spatial Structure	Shrubs in patches	Linear corridor	Linear corridor

Kees van Achterberg (Nationaal Natuurhistorisch Museum, Leiden, The Netherlands) and Max Fischer (Naturhistorisches Museum Wien, Austria). The only individuals that were not sent to a specialist were Exothecinae; they were considered as belonging to the same morphospecies. Eulophidae were identified by Paolo Navone (Di.Va. P.R.A.-Entomologia e Zoologia applicate all'ambiente "Carlo Vidano", Università di Torino, Grugliasco (TO), Italy), Pteromalidae and Tetracampidae by Hannes Baur (Naturhistorisches Museum Bern, Switzerland), and Figitidae (Eucoilinae) by Matt Buffington (University of California, Riverside, USA). Voucher specimens of each species have been deposited in the Entomological Collection of Dipartimento di Scienze e Tecnologie Agroambientali (DiSTA), Alma Mater Studiorum-Università di Bologna.

Data analysis

Shannon-Weaver indeces (H'), based on proportional abundance of species and dominance measures (Simpson index [D] and Berger-Parker index [d]), were calculated for each site. The species composition of the sites were compared by Sorenson's similarity index. The Jack-knifing technique was used to improve the estimate of H' and D. This method is recommended when a number of samples (in our case the different sites) have been taken (Magurran, 1988). The relationship between the number of sampled specimens per site and number of species per site was analysed by curvilinear regression ($y = a + b \ln x$).

Principal Component Analysis (PCA) was performed to ordinate the sites taking into account the samples of agromyzids and parasitoids in each year. Correspondence Analysis (CA) (Pielou, 1984; Manly, 1994), performed on the relative abundance of parasitoids, was carried out to ordinate the parasitoid species on the basis of plant species. This method of ordination was employed on the matrix $\boldsymbol{p} \times \boldsymbol{n}$, where $\boldsymbol{p}$ = plant species and $\boldsymbol{n}$ = parasitoid species.

The STATISTICA software for Windows StatSoft™ (1994) was used for statistical analysis.

Results and discussion

Agromyzid flies

A total of 599 agromyzid specimens representing eight genera (*Agromyza* Fallén, *Amauromyza* Hendel, *Calycomyza* Hendel, *Chromatomyia* Hardy, *Liriomyza* Mik, *Melanagromyza* Hendel, *Ophiomyia* Braschnikov and *Phytomyza* Fallén) and 24 species were collected (Figure 1; Table 1); 201 specimens (14 species) were reared in 1998 and 398 (21 species) in 1999. A species-by-plant account of the agromyzid flies recovered in each year from sites 1, 2 and 3 is presented in Tables 2, 3, 4 and 5, respectively.

The most abundant species was *Chromatomyia horticola* (Goureau); this agromyzid, which was represented at all sites in both years, accounted for 35.76% of emerged leafminers (Figure 1). The relative abundance of the closely related species *Chromatomyia syngenesiae* (Hardy) was much lower (0.77%). *Chromatomyia horticola* can be separated reliably from *C. syngenesiae* only on the basis of male genitalia (Griffiths, 1967), and 47 females reared from samples where no male emerged were conventionally denoted as *Chromatomyia* spp. (7.28%). These specimens were not taken in account in calculating species/specimens relationship (Figure 2) and biodiversity indices. Spencer (1990) considers *C. syngenesiae* essentially restricted to Asteraceae, and it is very likely that the 8 females reared from Brassicaceae and Plantaginaceae included in *Chromatomyia* spp. were actually *C. horticola*.

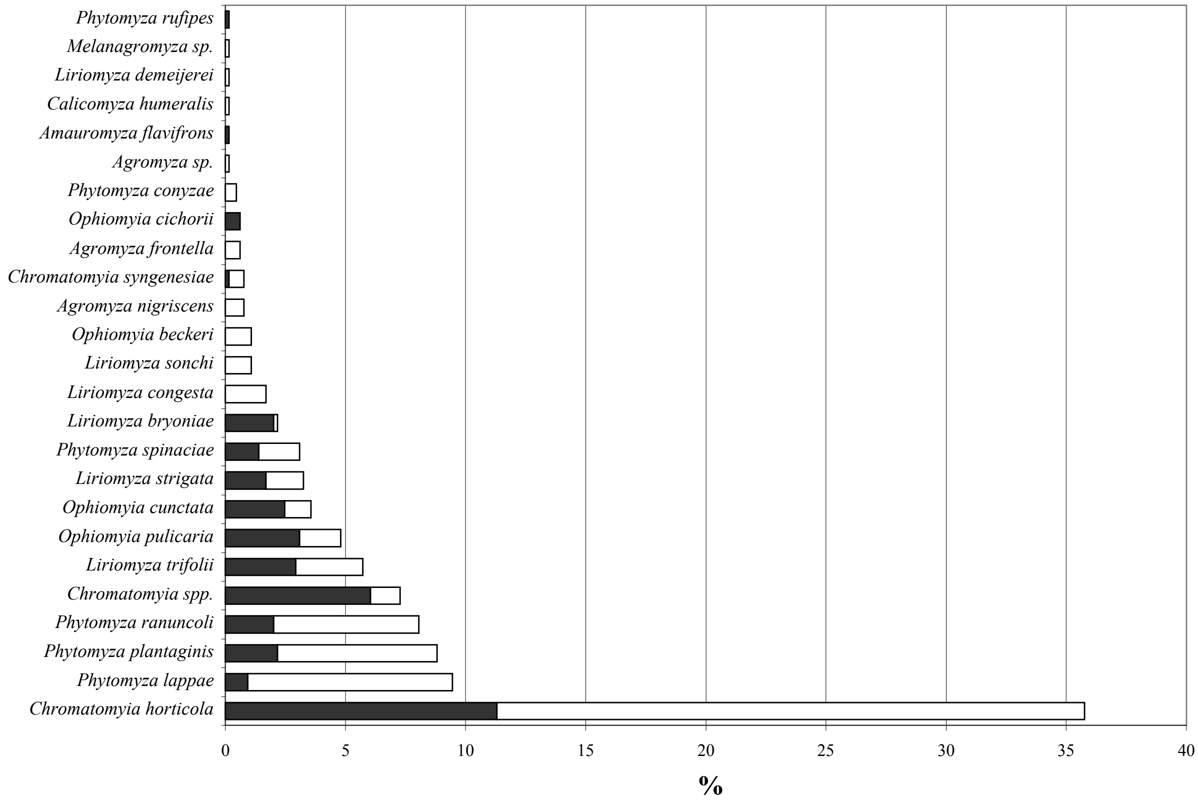

Figure 1. Relative abundance of each agromyzid species on the total specimens reared in both years of study (N = 646). Each year's contribution to the total is reported in different colors: black for 1998, and white for 1999.

Our data are in agreement with Spencer (1973) who reports that *C. horticola* is more common in the Mediterranean area than *C. syngenesiae*. *Chromatomyia horticola* showed a high degree of polyphagy, feeding on nine weed species belonging to three plant families (Asteraceae, Brassicaceae and Papaveraceae). *Chromatomyia syngenesiae* was reared only from *Picris echioides* L. and *Sonchus asper* (L.) Hill. Heavy infestations of *C. horticola* were sporadically reported on peas in eastern Asian countries (Spencer, 1973). Although many other crops and ornamentals are suitable hosts for this species, substantial damage is rarely recorded. *Chromatomyia syngenesiae* may cause severe aesthetic damage mainly on ornamentals (chrysanthemum and cineraria) in greenhouse (Cornelius and Godfray, 1984).

The six species belonging to the genus *Phytomyza* together accounted for 30.03% of emerged agromyzids (Figure 1). *Phytomyza lappae* Goureau was the second most abundant species (9.44%). Every specimen was reared form *Arctium lappa* L. collected in site 3, which was the only site where this weed was present. Frequently several mines occur in one leaf and even larger leaves can be completely eaten. *Phytomyza ranunculi* Schrank represented 8.05% of leafminers. Most of the specimens (44) were obtained from *R. velutinus*, and only eight specimens were reared from *Ranunculus bulbosus* L. Probably, as a consequence of the low density of *Ranunculus* spp. in site 1, *P. ranunculi* was almost absent in this area. All the adults of *Phytomyza plantaginis* Robineau-Desvoidy (8.82%) emerged from *Plantago lanceolata* L. It is a monophagous species that commonly occurs on Plantaginaceae in Europe (Spencer, 1990). The other three species *Phytomyza conyzae* Hendel,

Table 2. Total number of specimens of each agromyzid species reared from sampled host plants in three northern Italian agroecosystems.

Plant		Agromyzids reared
Families	Genus / Species	
Astereaceae	*Arctium lappa* L.	*P. lappae* (61), *L. bryoniae* (4)
"	*Artemisia vulgaris* L.	*L. trifolii* (2), *L. bryoniae* (1), *L. demeijerei* (1)
"	*Centaurea* L.	*C. horticola* (1)
"	*Cirsium arvense* (L.) Scopoli	*C. horticola* (74), *Chromatomyia* spp. (24), *P. spinaciae* (20), *L. strigata* (17), *L. trifolii* (16), *L. bryoniae* (5)
"	*Conyza canadensis* (L.) Cronquist	*C. humeralis* (1)
"	*Inula viscosa* L.	*P. conyzae* (3), *Melanagromyza* sp. (1)
"	*Lactuca serriola* L.	*C. horticola* (5), *L. trifolii* (4), *Chromatomyia* spp. (2), *L. bryoniae* (1), *L. strigata* (1),
"	*Lapsana communis* L.	*O. pulicaria* (9), *C. horticola* (8)
"	*Picris echioides* L.	*C. horticola* (17), *C. syngenesiae* (4), *Chromatomyia* spp. (3), *L. sonchi* (3), *L. bryoniae* (2), *L. trifolii* (2)
"	*Picris hieracioides* L.	*L. sonchi* (3), *L. trifolii* (2), *O. pulicaria* (2), *Chromatomyia* sp. (1)
"	*Sonchus asper* (L.) Hill	*C. horticola* (38), *O. cunctata* (20), *O. pulicaria* (15), *Chromatomyia* spp. (9), *O. beckeri* (7), *O. cicorii* (4), *L. strigata* (3), *L. trifolii* (3), *C. syngenesiae* (1), *L. bryoniae* (1), *L. sonchi* (1)
"	*Sonchus oleraceus* L.	*L. trifolii* (7), *O. pulicaria* (5), *O. cunctata* (3)
"	*Taraxacum* Weber	*L. trifolii* (1)
Caryophillaceae	*Silene alba* (Miller) Krause	*A. flavifrons* (1)
Brassicaceae	*Myagrum perfoliatum L.*	*C. horticola* (17), *Chromatomyia* spp. (3), *P. rufipes* (1)
"	*Rapistrum rugosum* (L.) Allioni	*C. horticola* (2), *Chromatomyia* sp. (1)
Geraniaceae	*Geranium columbinum* L.	*A. nigriscens* (1)
"	*Geranium dissectum* L.	*A. nigriscens* (4)
Fabaceae	*Medicago sativa* L.	*L. congesta* (6), *A. frontella* (4)
"	*Vicia sativa* L.	*L. congesta* (5)
Papaveraceae	*Papaver rhoeas* L.	*C. horticola* (69)
Plantaginaceae	*Plantago lanceolata* L.	*P. plantaginis* (57), *Chromatomyia* spp. (4)
Ranuncolaceae	*Ranunculus bulbosus* L.	*P. ranunculi* (8)
"	*Ranunculus velutinus* Tenore	*P. ranunculi* (44)
Urticaceae	*Urtica dioica* L.	*Agromyza* sp. (1)

Phytomyza rufipes Meigen and *Phytomyza spinaciae* Hendel were only slightly represented (0.46%, 0.15% and 3.10% respectively) and were found only in site 1.

The six *Liriomyza* species together accounted for 14.09% of the emerged agromyzids (Figure 1). The highly polyphagous *Liriomyza bryoniae* (Kaltenbach) (accounting for 2.17%), *Liriomyza strigata* (Meigen) (3.25%) and *Liriomyza trifolii* (Burgess) (5.73%) were present in every site. Even though potential host plants for these three species have been recorded in more than 30 botanical families (Spencer, 1990), every specimen reared in our study developed on plants belonging to Asteraceae (Table 2). Other favored families were absent from every transect and, with the exception of Fabaceae, the other sampled weeds are rarely mined by these *Liriomyza* spp.

In the United States *L. trifolii* is considered a major pest especially of celery and tomato (Zoebisch and Schuster, 1987; Parkman et al., 1989; Schuster et al., 1991; Patel et al., 2003), but its economic relevance in Europe appears to be limited to ornamentals and to some glasshouse vegetables (Minkenberg and van Lenteren, 1986; Tranfaglia and Arpaia, 1988; Del Bene, 1989).

Table 3. Agromyzid species found at site 1 listed by number of specimens reared within each weed and year. [a] Weed not present in the transect. [b] No adult emerged from mined leaves. [c] Weed present in the transect, but no signs of agromyzid infestation.

Agromyzid species	Weed species																													
	Centaurea spp.		*Cirsium arvense*		*Geranium colombinum*		*Inula viscosa*		*Lactuca serriola*		*Medicago sativa*		*Myagrum perfoliatum*		*Papaver rhoeas*		*Picris echioides*		*Picris hieracioides*		*Plantago lanceolata*		*Ranunculus velutinus*		*Sonchus asper*		*Taraxacum* spp.		Total	
	98^a	99	98	99	98^a	99	98^a	99	98	99	98^b	99	98	99	98	99	98	99	98	99	98	99	98^b	99	98	99	98^c	99	98	99
A. nigriscens	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
C. horticola	0	1	3	49	0	0	0	0	2	0	0	0	10	5	10	19	0	3	0	0	0	0	0	0	3	11	0	0	28	88
Chromatomyia spp.	0	0	10	0	0	0	0	0	2	0	0	0	1	2	0	0	0	0	0	0	3	0	0	0	3	1	0	0	19	3
C. syngenesiae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	3
L. bryoniae	0	0	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
L. congesta	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
L. sonchi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	3	0	0	0	0	0	0	0	0	0	6
L. strigata	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
L. trifolii	0	0	3	13	0	0	0	0	0	3	0	0	0	0	0	0	2	0	2	0	0	0	0	0	0	1	0	1	7	18
Melanagromyza sp.	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
O. beckeri	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
O. cunctata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	0	0	2	3
O. pulicaria	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	2
P. conyzae	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
P. plantaginis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	29	0	0	0	0	0	0	13	29
P. ranunculi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
P. rufipes	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
P. spinaciae	0	0	9	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	11
Total	0	1	27	73	0	1	0	4	6	3	0	6	12	7	10	19	2	9	2	5	16	29	0	1	8	17	0	1	83	176

Table 4. Agromyzid species found at site 2 listed by number of specimens reared within each weed and year. [a] Weed not present in the transect. [b] No adult emerged from mined leaves.

Agromyzid species	Weed species																											
	Cirsium arvense		*Lactuca serriola*		*Medicago sativa*		*Myagrum perfoliatum*		*Papaver rhoeas*		*Picris echioides*		*Picris hieracioides*		*Plantago lanceolata*		*Ranunculus bulbosus*		*Ranunculus velutinus*		*Rapistrum rugosum*		*Sonchus asper*		*Vicia sativa*		Total	
	98	99[a]	98	99[b]	98[b]	99	98[b]	99	98	99	98	99	98[a]	99	98	99	98	99	98	99	98	99[a]	98	99	98[b]	99	98	99
A. frontella	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
C. horticola	1	0	3	0	0	0	0	2	7	15	5	6	0	0	0	0	0	0	0	0	2	0	5	7	0	0	23	30
Chromatomyia spp.	1	0	0	0	0	0	0	0	0	0	1	2	0	1	1	0	0	0	0	0	1	0	2	2	0	0	6	5
L. bryoniae	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0
L. congesta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	5
L. strigata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0
L. trifolii	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0
O. cunctata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	4	0	0	10	4
P. plantaginis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	5
P. ranunculi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	4	8	24	0	0	0	0	0	0	11	28
Total	2	0	4	0	0	4	0	2	7	15	7	8	0	1	1	5	3	4	8	24	3	0	20	13	0	5	55	81

Table 5. Agromyzid species found at site 3 listed by number of specimens reared within each weed and year. [a] Weed not present in the transect. [b] No adult emerged from mined leaves. [c] Weed present in the transect, but no signs of agromyzid infestation.

Agromyzid species	Weed species																												Total	
	Arctium lappa		*Artemisia vulgaris*		*Cirsium arvense*		*Conyza canadensis*		*Geranium dissectum*		*Lapsana communis*		*Papaver rhoeas*		*Picris echioides*		*Plantago lanceolata*		*Ranunculus bulbosus*		*Ranunculus velutinus*		*Silene alba*		*Sonchus asper*		*Sonchus oleraceus*		*Urtica dioica*			
	98	99	98	99	98	99	98[a]	99	98[b]	99	98[a]	99	98	99	98[c]	99	98	99	98	99[b]	98	99	98	99[a]	98	99	98	99[b]	98[c]	99	98	99
Agromyza sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
A. nigriscens	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
A. flavifrons	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0
C. umeralis	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
C. horticola	0	0	0	0	0	21	0	0	0	0	0	8	14	4	0	3	0	0	0	0	0	0	0	0	8	4	0	0	0	0	22	40
Chromatomyia spp.	0	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	14	0
C. syngenesiae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1
L. bryoniae	4	0	1	0	3	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	1
L. demeijerei	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
L. sonchi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
L. strigata	0	0	0	0	7	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	9	10
L. trifolii	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	7	0	0	0	10	0
O. beckeri	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	6
O. cichorii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	4	0
O. cunctata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	3	0	0	0	4	0
O. pulicaria	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	15	0	5	0	0	0	20	9
P. lappae	6	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	55
P. plantaginis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	9	0	0	0	0	0	0	0	0	0	0	0	0	1	9
P. ranunculi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	10	0	0	0	0	0	0	0	0	2	10
Total	10	55	3	1	23	31	0	1	0	4	0	17	14	4	0	5	1	9	1	0	1	10	1	0	33	11	15	0	0	1	102	149

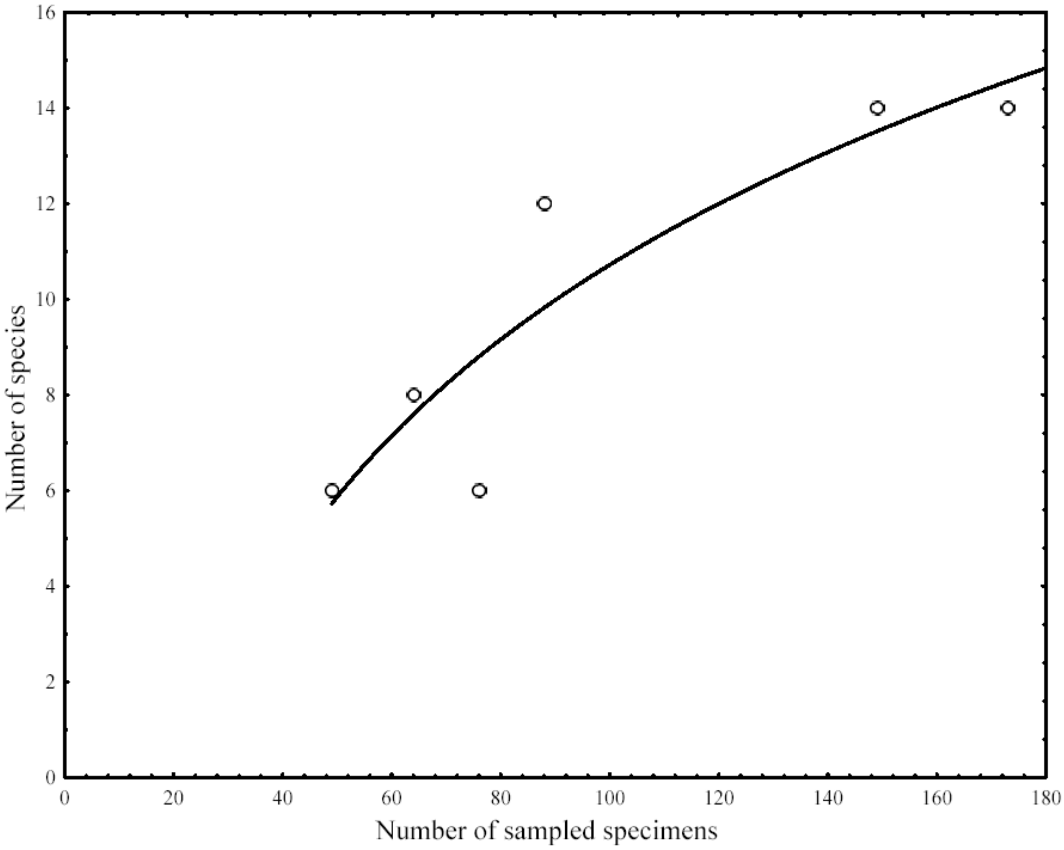

Figure 2. Species richness of agromyzids as a function of number of sampled specimens. Specimens of undetermined *Chromatomyia* spp. females were not considered in calculating the relationship.

Since its introduction in Italy (Arzone, 1979), no serious outbreaks were recorded in open field crops. *Liriomyza bryoniae* has relevant economic importance only on tomato in northern European heated glasshouses (Minkenberg and van Lenteren, 1986). Although *L. strigata* has a host range as extensive as that of the former *Liriomyza* species of economic importance, there are no records of serious damage caused by this species on crop plants.

Most of the weeds sampled by us are recorded as potential hosts for *Liriomyza huidobrensis* (Blanchard) (Spencer, 1990), the most dangerous agromyzid in Italy (Bosio, 1994; Lanzoni et al., 2003), but no specimens of this species were found by us in both years of this study.

Eleven specimens (1.70%) of *Liriomyza congesta* (Becker) were obtained in 1999; five of them were reared from *Vicia sativa* L. in site 2, and the other six specimens emerged from leaves of *Medicago sativa* L. collected in site 3. *Liriomyza congesta* is restricted to Fabaceae and has no economic importance (Spencer, 1973).

Seven specimens of *Liriomyza sonchi* Hendel altogether accounted for 1.08% of leafminers. This species is considered restricted to *Sonchus* in field, whereas in the laboratory *L. sonchi* occasionally bred on *Lactuca sativa* L. and on species in the genera *Aetheorrhiza*, *Crepis*, *Leontodon* and *Taraxacum* (Peschken and Derby, 1988). Only one specimen was reared on *Sonchus asper* (L.) Hill whereas three adults emerged from both *P. echioides* (one male) and *Picris hieracioides* L. (two males). *Liriomyza sonchi* was tested in the laboratory on *P. hieracioides* (Peschken and Derby, 1988), but rearing was unsuccessful. These are the first records of the fact that *L. sonchi* specimens were not reared from *Sonchus* in the field.

Only one specimen (0.15%) of *Liriomyza demeijerei* Hering was reared form leaves of *Artemisia vulgaris* L. collected in site 3.

The four species belonging to the genus *Ophiomyia* – *Ophiomyia beckeri* (Hendel), *Ophiomyia cichorii* Hering, *Ophiomyia cunctata* (Hendel) and *Ophiomyia pulicaria* (Meigen) – represented 10.06% of leafminers. Every *Ophiomyia* specimen was obtained from the family Asteraceae. The most important host plants were *S. asper* and *Sonchus oleraceus* L.. For *Ophiomyia* species found in this study no damage on crop plants is reported.

The relative abundance of the genus *Agromyza* was very low, representing only 1.55 % of agromyzid flies obtained. The four specimens of *Agromyza frontella* Rondani were reared from leaves of *M. sativa* collected in site 2. In 1968 this palearctic species was accidentally introduced in North America and it causes considerable damage on alfalfa (Drea et al., 1982). But in Europe no cases have been reported of *A. frontella* causing appreciable yield losses on this crop.

Agromyza nigriscens Hendel (0.77%) emerged from two Geraniaceae, *Geranium dissectum* L. and *Geranium columbinum* L., and it is reported by Spencer (1990) as the only agromyzid species known on Geraniaceae.

One female (0.15%) of another *Agromyza* species (reported as *Agromyza* sp.) emerged in 1999 from *Urtica dioica* L.

Amauromyza flavifrons (Meigen) reared from *Silene alba* (Miller) E. H. Krause, *Calycomyza humeralis* von Roser from *Conyza canadensis* (L.) Cronquist and *Melangromyza* sp. from *Inula viscosa* L. were represented by one specimen each (0.15%) (Figure 1).

Agromyzids mined leaves and/or stems of nine families, 21 genera and 25 species of weeds in the studied areas (Table 2). Over 80% of agromyzids were reared from seven plant species (*C. arvense*, *S. asper*, *Papaver rhoeas* L., *A. lappa*, *P. lanceolata, R. velutinus* and *P. echioides*), and other weeds proved to be only lightly infested (Figure 3).

The most important source of leafminers was *C. arvense* (Figure 3), a suitable host for six agromyzid species (Table 2). *Sonchs asper*, which was the second weed in relative abundance of leafminers (Figure 3), could harbour 10 species. Five agromyzid species were found on *P. echioides* (Table 2). Mainly monophagous agromyzids were reared on the other heavily infested plants (Table 2). The exception was *P. rhoeas* that was mined by *C. horticola*. The Asteraceae, represented by 13 plant species, was the most important botanical family harbouring over 65% of the leafminers belonging to 16 species.

The number of specimens collected varied considerably from one year to the other and among sites as well. Undetermined *Chromatomyia* spp. females were not considered in calculating indices and not included in number of specimens reared and reported in Table 6. Eighty-three agromyzid specimens representing eight species were recovered from site 1 in 1998. During 1999, 176 flies belonging to 14 species were obtained from the same site. From foliage collected in site 2, 55 specimens (six species) and 81 specimens (six species) emerged in 1998 and 1999 respectively. In 1998, the highest number of specimens (102) and the highest species richness (12) was observed at site 3. In 1999, 149 agromyzid adults belonging to 14 species were reared from this site. These differences were also reflected in biodiversity indices.

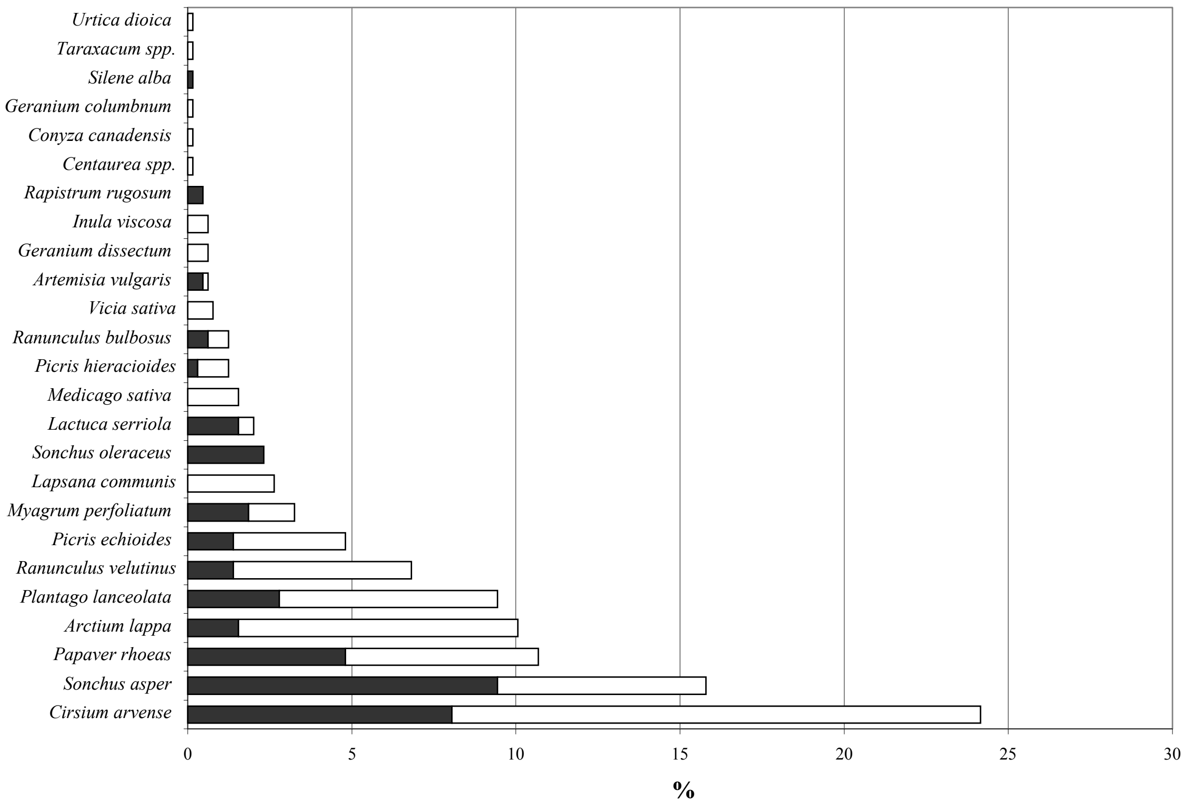

Figure 3. Relative abundance of agromyzid specimens emerged from each sampled weed species on the total number of specimens reared in both years of study (N = 646). Each year's contribution to the total is reported in different colours: black for 1998 and white for 1999.

Table 6. Estimates of diversity of agromyzids occurring on weeds in three northern Italian agroecosystems. The results are derived from Shannon-Weaver index (H') and reciprocal forms of Simpson (1/D) and Berger-Parker (1/d) indices. Undetermined *Chromatomyia* spp. females were not considered in calculating indices and not included in number of specimens reared.

	Site 1		Site 2		Site 3		Overall	
	1998	1999	1998	1999	1998	1999	1998	1999
# of specimens	64	173	49	76	88	149	201	398
# of species	8	14	6	6	12	14	14	21
H'	1.585	1.669	1.355	1.403	2.422	1.851	2.422[a]	2.419[a]
1/D	3.899	3.320	3.313	3.373	6.860	4.504	6.393[a]	5.623[a]
1/d	2.286	1.966	2.130	2.533	4	2.709	2.753	2.519

[a] Jack-knife estimates.

Site 3 had the highest number of agromyzid species, the highest biodiversity and the lowest dominance during both years. This may reflect the higher floristic richness and the higher complexity of the ecological net distinguishing this area. Non-intensive agriculture practices and the lack of chemical sprays also characterised site 3. It is likely that the simplified plant composition and chemical management on nearby crops negatively affected the agromyzid community at site 2, which showed the lowest number of species and lowest values of Shannon-Weaver index in both years. The highest differences in number of both species and specimens between 1998 and 1999 were observed at site 1. The Shannon-Weaver index slightly increased across years, but the Simpson and Berger-Parker indices decreased from 3.899 to 3.320 and from 2.286 to 1.966, respectively. The reason for this discrepancy is due to the increase of the relative abundance of *C. horticola*, which accounted for over 50% of the total specimens of site 1 in 1999. This increment more strongly affected the dominance indices that are more influenced by abundant species than the Shannon index, which is weighted in favour of rare ones (Magurran, 1988).

Jack-knife estimates of Shannon-Weaver and Simpson indices per year (Table 6) were in agreement in indicating an overall high level of diversity. Values of the Shannon-Weaver index were also largely coincident in both years, whereas the Simpson and Berger-Parker indices pointed out lower diversity in 1999 than in 1998. This discrepancy is to be expected since both the common species abundance and the number of rare species increased from 1998 to 1999. Higher relative abundance of common species, which was revealed by dominance indices, was offset by a higher number of rare species in the Shannon-Weaver index.

In Table 7 the Sorenson index values calculated by considering all the species sampled in both years from each site are reported. As expected, site 2 and site 3, which were characterised by the most different environmental conditions, showed the least amount of similarity (0.51). Only seven agromyzids were reared in every site. All of the four truly polyphagous species (*C. horticola*, *L bryoniae*, *L. strigata* and *L. trifolii*), feeding on a wide range of plants, were able to colonise each site. The other three leafminers listed in all sites, *O. cunctata*, *P. plantaginis*, and *P. ranunculi*, were restricted to *Sonchus*, *P. lanceolata* and *Ranunculus* respectively, but, in spite of their narrower host range, they were constantly present in association with these widespread plants.

The variation in composition of weeds across years (Tables 3, 4, and 5) could explain to a great extent the variation in agromyzid species sampled, as many of them are restricted to a single plant. In contrast, since the majority of flies emerged from plants that were present at each site in both years, weed composition probably had less influence on agromyzid density. The increase in the number of specimens reared in 1999 could be related to other factors, including climatic conditions and intrinsic instability of studied agroecosystems.

Table 7. Sorenson index of similarity (C_s) for comparison of the agromyzid species composition between sampled sites

C_s	Site 1	Site 2	Site 3
Site 1	1	0.6154	0.6857
Site 2	0.6154	1	0.5185
Site 3	0.6857	0.5185	1

As shown in Figure 2, the number of species found at each site was significantly positively correlated with the number of specimens sampled (y = -21.529 + 7.002 ln x, $F_{(1,4)}$ = 17.57, P = 0.0138, r = 0.9025). The fitted curve seems to approach a maximum value, which can be considered the maximum number of agromyzid species infesting the sampled plants. This evidence confirms the consistency of our sampling. Nevertheless, species with different feeding habits - i.e. internal stem-borers, leafminers on trees, and gall-causers – may not have been sampled at all. Therefore, the species diversity of agromyzids living in the studied areas may still be underestimated. Malaise traps and other methods to collect and sample adults would give a better estimation of the whole agromyzid fauna, but are not suitable to study trophic relationships between leafminers and weeds.

A PCA performed on the relative abundances of agromyzid species in each site revealed a low variability between years (Figure 4), and the samples taken from the same sites in the two years were closely grouped together.

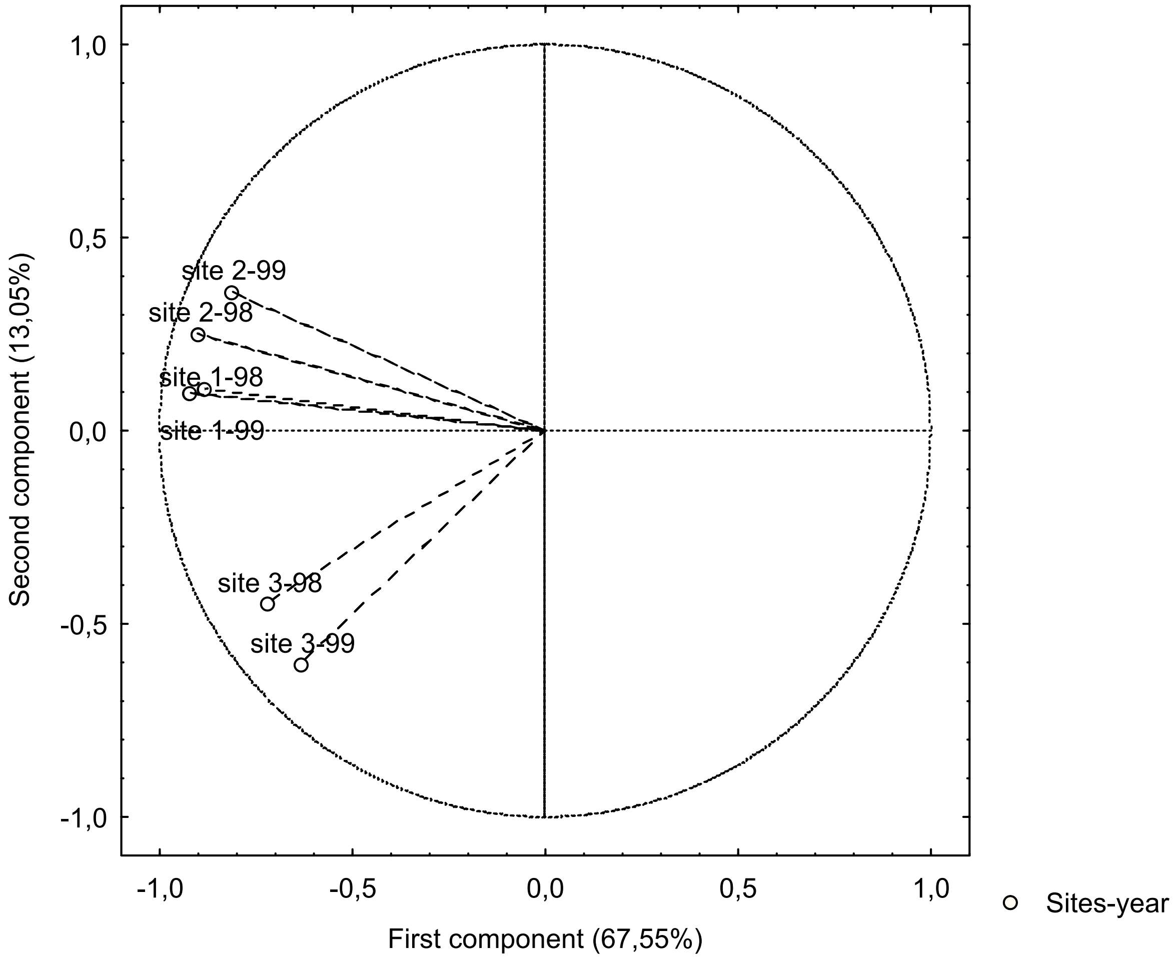

Figure 4. Principal Component Analysis performed on agromyzids.

Parasitoids

A total of 998 hymenopteran specimens, representing five families, 23 genera, and 53 species, were reared from leafminers infesting weed foliage. A species account of the parasitoids recovered in both years from each site is presented in Table 8. Eulophidae were the most abundant family (67.64%), followed by Braconidae (28.86%), Eucoilinae (1.40%), Tetracampidae (1.40%) and Pteromalidae (0.7 %). Braconids were the most species rich family accounting for 28 species, Eulophidae were represented by 19 species, Pteromalidae by four species, and Eucoilinae and Tetracampidae by one species each. The dominant parasitoid was the eulophid *Pediobius metallicus* (Nees), representing 18.17% of the total, followed by *Diglyphus isaea* (Walker) (12.73%), and *Neochrysocharis formosa* (Westwood) (10.82%). The most abundant braconid parasitoid was *Dacnusa maculipes* Thomson (9.62%), the fourth species in order of abundance. Besides these, only eight other parasitoids showed relative abundances higher than 2%. All these high-density species found suitable agromyzid hosts on a wide range of plants. For example, *P. metallicus* and *D. isaea* were reared from 14 weed species, *N. formosa* from 18 weeds and *D. maculipes* from 13 plant species. *Chorebus buhri* Griffiths and *Dacnusa plantaginis* Griffiths, although showing relative abundances of 1.9 and 2.1% respectively, were both restricted to *Plantago lanceolata* L.

Six braconids, one eulophid and two pteromalids marked with an asterisk in Table 8 are new records for the Italian fauna.

Parasitoids were reared from 24 agromyzids infesting the foliage of 34 weeds belonging to 14 plant families (Table 9). Over 80% of wasps were recovered from 10 plant species: *C. arvense*, *P. lanceolata*, *S. asper*, *P. rhoeas*, *P. echioides, Lactuca serriola* L., *Myagrum perfoliatum* L., *R. velutinus*, *A. lappa*, *M. sativa* (Figure 5).

The other sampled plants were only slightly mined or sporadically represented within the transects. *Cirsium arvense*, the single most important source of parasitoids, was suitable for 26 different species (Table 3). From *P. lanceolata*, *S. asper*, and *P. rhoeas*, each accounting for ≈10% of emerged wasps, 14, 22, and 10 parasitoid species were reared, respectively. Also weeds infested mainly by monophagous leafminers, such as *P. lanceolata*, *R. velutinus* and *A. lappa* (Masetti et al., 2004), showed a high richness in parasitoid species.

The number of parasitoid species recovered from each plant was positively correlated with the total number of insects (agromyzids + parasitoids) emerged per weed ($r = 0.87$, $P < 0.01$) (Figure 6).

Correspondence analysis was carried out to ordinate the relative abundances of parasitoid species on the basis of plant species (Figure 7). Most plant and parasitoid species overlapped forming a single cluster. In only one case, a strong relationship between parasitoid species and weeds was detected: *Neochrysocharis* sp. nr. *arvensis* Graham and *Chorebus iridis* Griffiths were strongly associated with stems of *Sonchus*.

The total number of individuals collected increased from 387 (38.8%) in 1998 to 611 (61.2%) in 1999. Twenty-eight species (52.8%) were recovered in both years, whereas 14 species were sampled exclusively in 1998 and 11 species only in 1999. This variation in species richness and composition between years was almost entirely due to the irregular occurrence of low-density parasitoids (< 2% relative abundance). On the other hand, presence and relative abundance of the dominant parasitoid species were stable across the years.

The percentage of parasitism (Table 10) ranged from 41.4% (site 3 in 1998) to 69.9% (site 1 in 1998). The overall percentage of parasitism, calculated by pooling all collected data, was 60.7%, which can be considered as an important contribution to the reduction of agromyzid numbers.

Table 8. List of the parasitoids sampled in 1998 and 1999 at each site. The overall relative abundances are also reported. Species marked with an asterisk are new records for Italy.

Family	Species	Site 1		Site 2		Site 3		Total	Relative abundance %
		1998	1999	1998	1999	1998	1999		
Braconidae	*Aphanta hospita* Foerster	0	0	1	0	1	0	2	0,20
"	*Aphanta sasakawai** (Takada)	0	2	0	1	0	1	4	0,40
"	*“Bitomus” pamboloides** (Tobias)	0	0	0	0	1	0	1	0,10
"	*Chorebus alecto* (Morely)	0	9	0	0	0	0	9	0,90
"	*Chorebus avestus* (Nixon)	0	0	0	0	2	5	7	0,70
"	*Chorebus buhri** Griffiths	0	4	0	9	0	6	19	1,90
"	*Chorebus daimenes** (Nixon)	5	4	0	0	1	2	12	1,20
"	*Chorebus fallaciosae** Griffiths	0	0	0	3	0	0	3	0,30
"	*Chorebus iridis* Griffiths	0	0	0	0	1	0	1	0,10
"	*Chorebus leptogaster* Haliday	0	0	1	2	0	2	5	0,50
"	*Chorebus* sp. nr. *Asphodeli* Griffiths	0	1	0	0	0	0	1	0,10
"	*Dacnusa maculipes* Thomson	27	44	6	12	0	7	96	9,62
"	*Dacnusa plantaginis** Griffiths	0	5	1	9	0	6	21	2,10
"	*Dacnusa pubescens* (Curtis)	0	1	0	0	0	0	1	0,10
"	*Dacnusa sibirica* Telenga	1	6	3	7	3	2	22	2,20
"	Exothecinae	0	0	0	0	2	0	2	0,20
"	*Heterolexis balteata* (Thomson)	0	0	0	0	0	1	1	0,10
"	*Opiostomus impatientis* (Fischer)	0	1	1	1	1	2	6	0,60
"	*Opius caricivorae* Fischer	4	0	4	0	1	0	9	0,90
"	*Opius gracilis* Fischer	0	1	1	0	0	5	7	0,70
"	*Opius levis* Wesmael	0	1	0	3	0	0	4	0,40
"	*Opius lonicerae* Fischer	0	1	0	0	0	0	1	0,10
"	*Opius pallipes* Wesmael	3	6	2	0	0	6	17	1,70
"	*Opius tersus* (Foerster)	1	0	1	0	1	0	3	0,30
"	*Phaedrotoma diversa* (Szépligeti)	1	0	1	0	0	0	2	0,20
"	*Phaedrotoma esigua* (Wesmael)	1	9	2	6	0	10	28	2,81
"	*Phaedrotoma longiradialis* (Fischer)	1	0	0	0	1	0	2	0,20
"	*Phaedrotoma* sp. nr. *seiunctus* (Fischer)	1	0	1	0	0	0	2	0,20
Eulophidae	*Aprostocetus* sp.	3	0	0	0	0	0	3	0,30
"	*Chrysocharis entedonoides* (Walker)	0	0	0	0	5	1	6	0,60
"	*Chrysocharis gemma* (Walker)	0	1	0	0	0	0	1	0,10
"	*Chrysocharis liriomyzae* Delucchi	0	0	2	0	0	4	6	0,60
"	*Chrysocharis pentheus* (Walker)	2	2	0	2	4	28	38	3,81
"	*Chrysocharis pubicornis* (Zetterstedt)	17	39	0	0	2	4	62	6,21
"	*Chrysocharis viridis* (Nees)	0	0	0	0	2	1	3	0,30
"	*Diaulinopsis arenaria* (Erdös)	3	6	12	1	0	0	22	2,20
"	*Diglyphus crassinervis* Erdös	5	11	7	6	0	0	29	2,91
"	*Diglyphus isaea* (Walker)	36	21	14	40	2	14	127	12,73
"	*Diglyphus poppoea* Walker	1	1	5	1	2	7	17	1,70
"	*Diglyphus pustzensis* * (Erdös & Novick)	5	6	1	3	2	6	23	2,30
"	*Hemiptarsenus ornatus* (Nees)	1	5	5	1	0	3	15	1,50
"	*Hemiptarsenus unguicellus* (Zetterstedt)	1	0	0	2	0	0	3	0,30
"	*Neochrysocharis formosa* (Westwood)	10	51	19	9	11	8	108	10,82
"	*Neochrysocharis* sp. nr. *arvensis* Graham	0	0	3	0	10	3	16	1,60
"	*Pediobius metallicus* (Nees)	54	69	22	10	8	18	181	18,14
"	*Pnigalio pectinicornis* (L.)	0	0	3	0	3	0	6	0,60
"	*Pnigalio soemius* (Walker)	0	6	0	2	0	1	9	0,90
Eucoilinae	*Gronotoma* sp. nr. *sculpturata* (Förster)	0	3	1	1	3	6	14	1,40
Tetracampidae	*Epiclerus panyas* (Walker)	9	3	0	1	1	0	14	1,40
Pteromalidae	*Halticoptera circulus* (Walker)	0	0	0	0	2	0	2	0,20
"	*Sphegigaster brevicornis** (Walker)	1	0	0	0	0	0	1	0,10
"	*Sphegigaster stepicola** Bouček	0	0	2	0	0	0	2	0,20
"	*Stenomalina gracilis* (Walker)	0	0	1	1	0	0	2	0,20
Total		193	319	122	133	72	159	998	

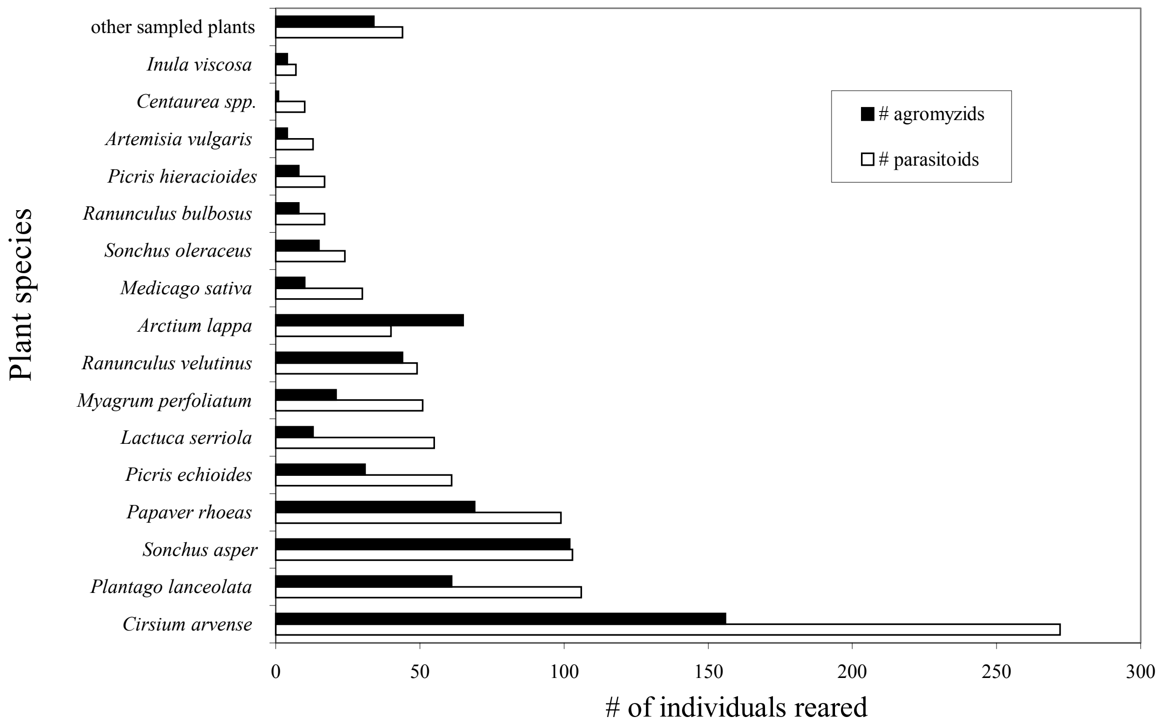

Figure 5. Relative abundance of agromyzid and parasitoid specimens emerged from each sampled weed species (N = 599 for agromyzids; N = 998 for parasitoids).

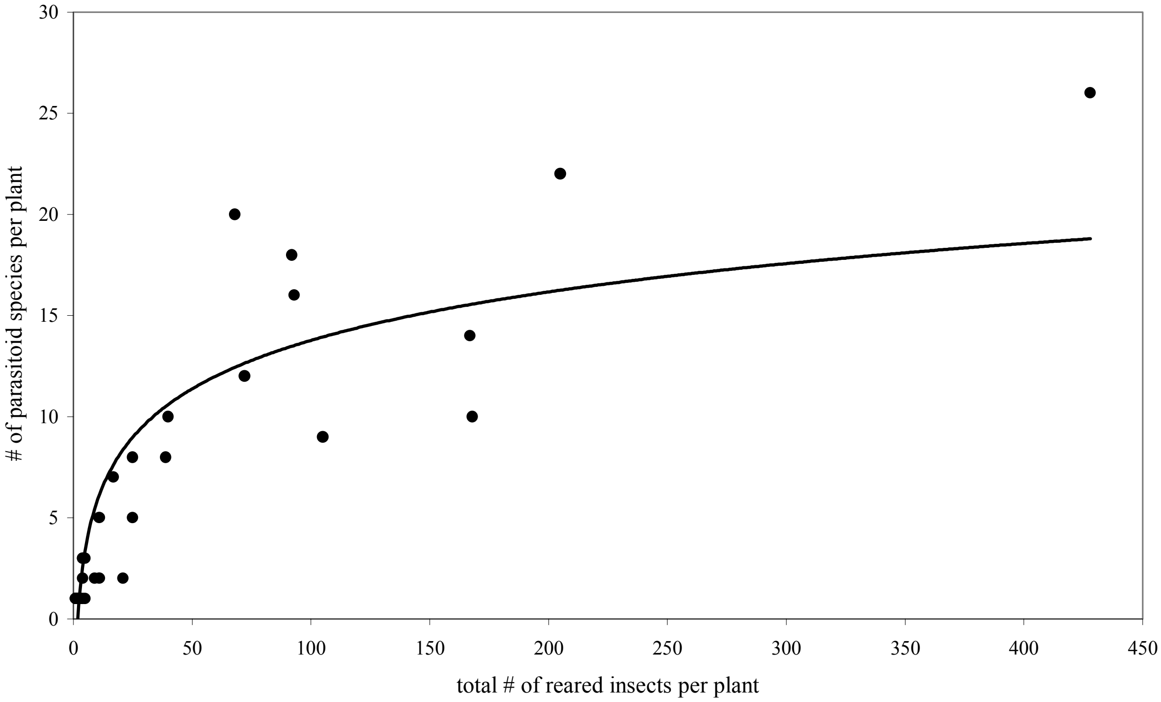

Figure 6. Correlation between the number of parasitoid species per plant against the total number of insects (agromyzid + parasitoids) per plant (Equation: $Y = -2.14 + 3.45 \ln(x)$; $R = 0.87$; $P<0.01$).

Table 9. List of parasitoids reared from each sampled plant.

Plant genus / species	Site and year of sampling	Parasitoids reared	Total # of parasitoid individuals reared	Total # of parasitoid species reared	Total # of agromyzid individuals reared	Total # of agromyzid species reared
Cirsium arvense (L.) Scopoli	**1** (98-99) **2** (98) **3** (98-99)	*P. metallicus* (67), *C. pubicornis* (40), *D. maculipes* (29), *N. formosa* (29), *D. isaea* (22), *O. pallipes* (13), *D. pustzensis* (10), *D. crassinervis* (9) *C. daimenes* (8), *E. panyas* (8), *C. pentheus* (7), *P. exigua* (6), *O. caricivorae* (5), *Aprostocetus* sp.(3), *D. arenaria* (3), *P. soemius* (3) *A. hospita* (1), *A. sasakawai* (1), *B. pamboloides* (1), *P. diversa* (1), *P. longiradialis* (1), *C. entedonoides* (1), *C. gemma* (1), *D. poppoea* (1), *H. ornatus* (1), *S. brevicornis* (1)	272	26	156	6
Plantago lanceolata L.	**1** (98-99) **2** (98-99) **3** (99)	*D. plantaginis* (21), *C. buhri* (19), *N. formosa* (19), *P. metallicus* (14), *D. isaea* (13), *D. maculipes* (6), *P. exigua* (4), *H. ornatus* (3), *C. pubicornis* (2), *D. sibirica* (1), *P.* sp. nr *seiunctus* (1), *D. arenaria* (1), *H. unguicellus* (1), *E. panyas* (1)	106	14	61	2
Sonchus asper (L.) Hill	**1** (98-99) **2** (98-99) **3** (98-99)	*D. isaea* (16), *D. maculipes* (11), *P. metallicus* (10), *G.* sp. nr. *sculpturata* (10), *N.* sp. nr. *arvensis* (9), *N. formosa* (8), *D. arenaria* (6), *D. crassinervis* (6), *C. liriomyzae* (5), *C. leptogaster* (4), *D. sibirica* (3), *C. pentheus* (2), *D. poppoea* (2), *P. pectinicornis* (2), *S. stepicola* (2), *C. iridis* (1), *O. gracilis* (1), *P. exigua* (1), *C. pubicornis* (1), *D. pustzensis* (1), *H. ornatus* (1), *P. soemius* (1)	103	22	102	10
Papaver rhoeas L.	**1** (98-99) **2** (98-99) **3** (98-99)	*P. metallicus* (44), *D. maculipes* (18), *D. isaea* (16), *P. exigua* (5), *C. pubicornis* (4), *N. formosa* (4), *N.* sp. nr. *arvensis* (3), *E. panyas* (3), *D. pustzensis* (1), *P. soemius* (1)	99	10	69	1
Picris echioides L.	**1** (98-99) **2** (99) **3** (99)	*P. metallicus* (14), *C. leptogaster* (7), *P. exigua* (7), *D. isaea* (6), *O. gracilis* (5), *D. pubescens* (3), *C. pubicornis* (3), *N.* sp. nr. *arvensis* (3), *D. sibirica* (2), *D. pustzensis* (2), *H. ornatus* (2), *C. fallaciosae* (1), *P.* sp. nr *seiunctus* (1), *C. pentheus* (1), *H. unguicellus* (1), *N. formosa* (1), *P. pectinicornis* (1), *G.* sp. nr. *sculpturata* (1)	61	18	31	6
Lactuca serriola L.	**1** (98-99) **2** (98)	*N. formosa* (10), *C. alecto* (9), *P. metallicus* (8), *C. pubicornis* (5), *D. arenaria* (3), *D. maculipes* (2), *O. pallipes* (2), *D. pustzensis* (2), *E. panyas* (2), *G.* sp. nr. *sculpturata* (2), *C. daimenes* (1), *D. sibirica* (1), *O. tersus* (1), *P. exigua*(1), *C. pentheus* (1), *D. crassinervis* (1), *D. isaea* (1), *H. ornatus* (1), *H. unguicellus* (1),*P. soemius* (1)	55	20	13	5

Table 9. (continued)

Plant genus / species	Site and year of sampling	Parasitoids reared	Total # of parasitoid individuals reared	Total # of parasitoid species reared	Total # of agromyzid individuals reared	Total # of agromyzid species reared
Myagrum perfoliatum L.	**1** (98-99) **2** (98-99)	*D. isaea* (23), *P. metallicus* (10), *C. pubicornis* (4), *N. formosa* (4), *D. maculipes* (3), *A. sasakawai* (1), *C.* sp. nr. *asphodeli* (1), *D. pubescens* (1), *D. sibirica* (1), *O. impatientis* (1), *P. diversa* (1), *D. pustzensis* (1)	51	12	21	2
Ranunculus velutinus Tenore	**1** (98-99) **2** (98-99) **3** (98-99)	*D. isaea* (14), *D. crassinervis* (8), *D. pubescens* (6), *C. leptogaster* (4), *C. buhri* (3), *O. caricivorae* (3), *S. gracilis* (2), Exothecinae (1), *O. levis* (1), *O. pallipes* (1), *P. exigua* (1), *C. liriomyzae* (1), *C. pentheus* (1), *C. viridis* (1), *H. ornatus* (1), *N. formosa* (1)	49	16	44	1
Arctium lappa L.	**3** (98-99)	*C. pentheus* (21), *C. avestus* (7), *D. maculipes* (2), *O. impatientis* (2), *C. viridis* (2), *N. formosa* (2), *H. circulus* (2), *A. hospita* (1), Exothecinae (1)	40	9	65	2
Medicago sativa L.	**1** (98-99) **2** (98-99) **3** (98)	*D. arenaria* (8), *D. poppoea* (5), *N. formosa* (5), *O. impatientis* (3), *D. isaea* (3), *P. pectinicornis* (2), *O. tersus* (1), *P. esigua* (1), *P. longiradialis* (1), *P. metallicus* (1)	30	10	10	2
Sonchus oleraceus L.	**2** (98-99) **3** (98-99)	*D. poppoea* (7), *D. pustzensis* (5), *P. metallicus* (4), *C. entedonoides* (3), *C. pentheus* (2), *D. isaea* (1), *N. formosa* (1), *N.* sp. nr. *arvensis* (1)	24	8	15	3
Picris hieracioides L.	**1** (99) **2** (98-99) **3** (99)	*N. formosa* (6), *D. crassinervis* (5), *C. daimenes* (1), *O. loniceare* (1), *D. arenaria* (1), *D. pustzensis* (1), *H. ornatus* (1), *P. metallicus* (1)	17	8	8	4
Ranunculus bulbosus L.	**1** (99) **2** (98-99)	*N. formosa* (7), *D. isaea* (5), *O. levis* (3), *O. caricivorae* (1), *O. pallipes* (1)	17	5	8	1
Artemisia vulgaris L.	**3** (98-99)	*N. formosa* (6), *C. avestus* (2), *O. gracilis* (1), *C. pentheus* (1), *C. pubicornis* (1), *D. poppoea* (1), *P. pectinicornis* (1)	13	7	4	3
Centaurea L.	**1** (99)	*D. maculipes* (7), *D. sibirica* (3)	10	2	1	1
Inula viscosa L.	**1** (99)	*N. formosa* (2), *P. metallicus* (2), *D. isaea* (1), *D. poppoea* (1), *P. soemius* (1)	7	5	4	2
Geranium dissectum L.	**1** (99) **3** (99)	*D. maculipes* (4), *H. balteata* (1)	5	2	4	1
Trifolium L.	**1** (98-99) **2** (99)	*D. maculipes* (2), *C. pentheus* (1), *N. formosa* (1)	4	3	0	0

Table 9. (continued)

Plant genus / species	Site and year of sampling	Parasitoids reared	Total # of parasitoid individuals reared	Total # of parasitoid species reared	Total # of agromyzid individuals reared	Total # of agromyzid species reared
Taraxacum Weber	**2** (99) **3** (98)	*C. pubicornis* (2), *C. entedonoides* (1), *G.* sp. nr. *sculpturata* (1)	4	3	1	1
Veronica L.	**2** (99)	*D. isaea* (3), *D. maculipes* (1)	4	2	0	0
Lapsana communis L.	**3** (99)	*P. metallicus* (3), *H. ornatus* (1)	4	2	17	2
Senecio vulgaris L.	**2** (98)	*H. ornatus* (4)	4	1	0	0
Silene alba (Miller) Krause	**3** (98)	*O. tersus* (1), *C. pentheus* (1), *N. formosa* (1)	3	3	1	1
Avena fatua L.	**2** (99)	*D. isaea* (3)	3	1	0	0
Solanum dulcamara L.	**3** (98)	*D. sibirica* (2)	2	1	0	0
Rapistrum rugosum (L.) Allioni	**2** (98)	*P. metallicus* (2)	2	1	3	1
Phacelia tanacetifolia Bentham	**1** (99)	*P. exigua* (2)	2	1	0	0
Geranium columbinum L.	**1** (99)	*P. soemius* (2)	2	1	1	1
Sorghum halepense L.	**2** (99)	*N. formosa* (1)	1	1	0	0
Scrophulariacea *sp.*	**2** (99)	*D. sibirica* (1)	1	1	0	0
Conyza canadensis (L.) Cronquist	**3** (99)	*P. metallicus* (1)	1	1	1	1
Chenopodium album L.	**1** (99)	*D. sibirica* (1)	1	1	0	0
Ballota nigra L.	**3** (99)	*C. entedonoides* (1)	1	1	0	0

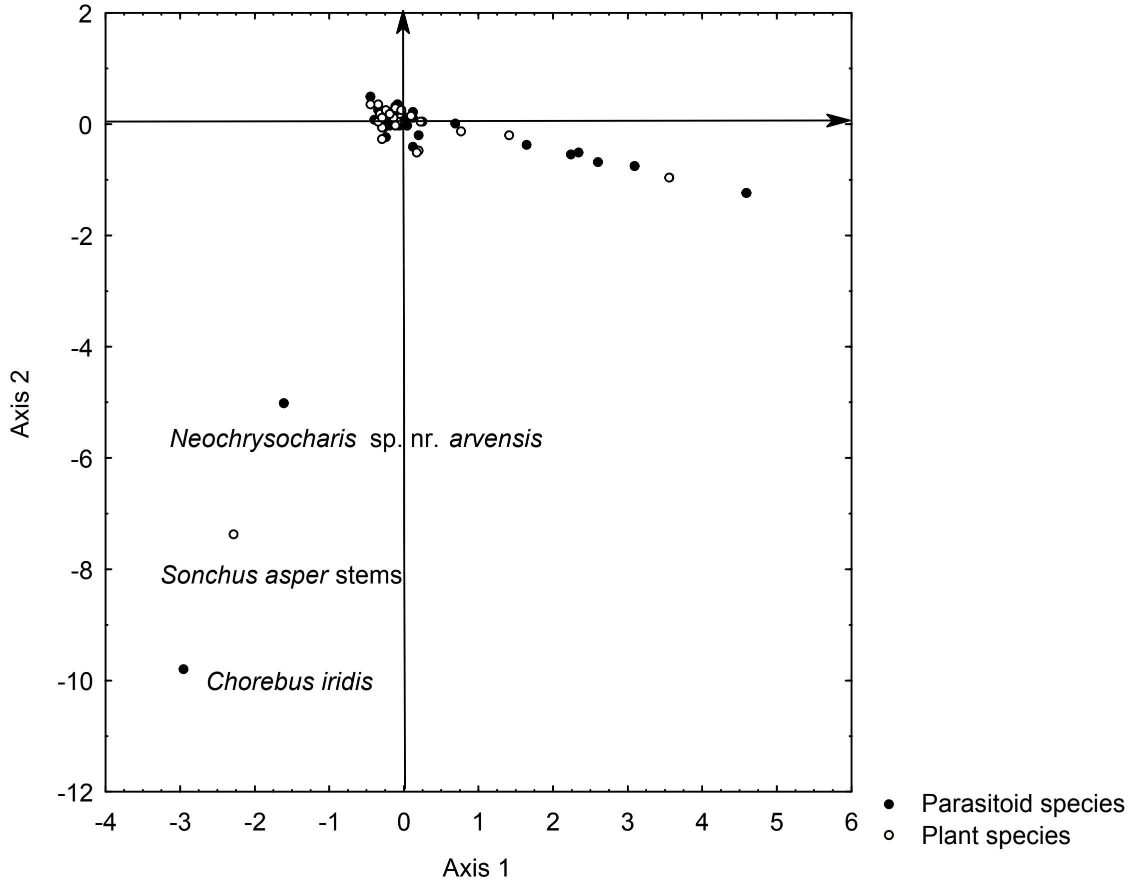

Figure 7. Correspondence analysis performed on the relative abundance of parasitoids and plant species.

Table 10. Percentage of parasitism of agromyzids at the sampled sites in 1998 and 1999.

Sites	% parasitism	
	1998	1999
Site 1	69.92	64.44
Site 2	68.92	62.15
Site 3	41.38	51.62
Total	61.72	60.10

Table 11 reports the biodiversity indices, including the Shannon-Weaver and the Simpson indices for each site in both years. Consistent discrepancies in the number of reared individuals were observed between sites as well as from one year to the other within the same site. Contrarily, the total number of species varied to a lesser extent. The mean index values for parasitoids, calculated by pooling the sites and the years, were 2.67 (Shannon-Weaver) and 11.04 (Simpson), indicating a relatively high overall level of diversity. In all the sites sampled during the two years, Simpson's index showed a wider variation range than the Shannon-Weaver index.

Sites sampled in 1998 and 1999 were ordered by PCA on a matrix calculated on the abundances of parasitoid species in each site and year. This multivariate technique pointed out strong between-year variability for each site (Figure 8). In other words, a site sampled in different years showed lower similarity in comparison with different sites in the same year.

The correlation matrix calculated by Sorensen's similarity index and after pooling the species sampled in both years from each site, is reported in Table 12.

Table 11. Biodiversity indices at the sampled sites in 1998 and 1999.

	Site 1		Site 2		Site 3	
	1998	1999	1998	1999	1998	1999
No. species	24	29	27	24	25	27
No. individuals	193	319	122	133	72	159
Shannon-Weaver	2.33	2.56	2.74	2.56	2.88	2.92
Simpson	6.93	8.81	11.64	8.26	15.88	14.71

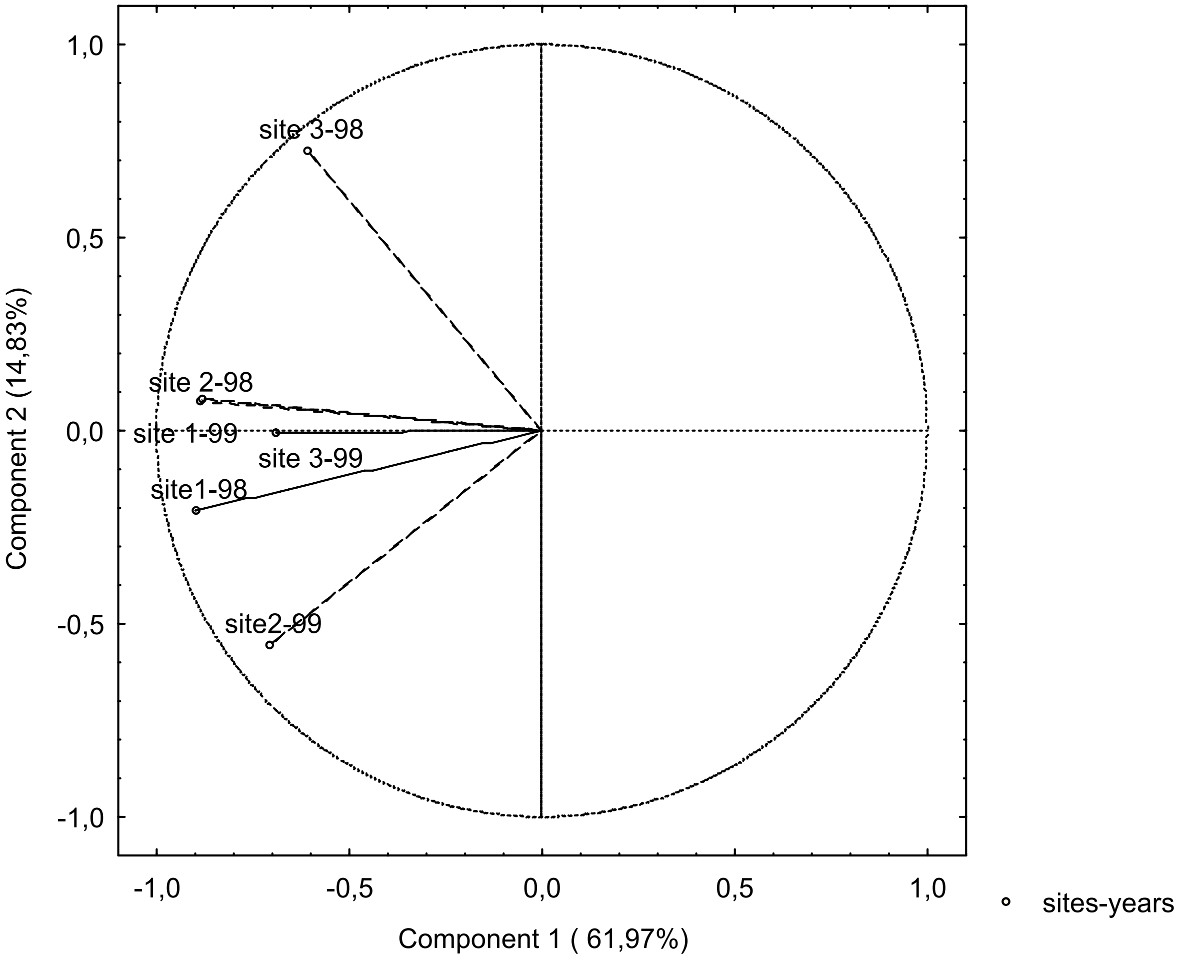

Figure 8. Principal Component Analysis performed on parasitoids.

Table 12 - Correlation matrix calculated by Sorenson's similarity index.

	Site 1	Site 2	Site 3
Site 1	1	0,75	0,69
Site 2	0,75	1	0,73
Site 3	0,69	0,73	1

Weed–agromyzid–parasitoid relationships

The total number of individuals reared and the species composition varied considerably both for leafminers and related parasitoids. Agromyzids revealed a high degree of among-sites variability, which was reflected by high discrepancies in diversity indices and low similarity between sites. A PCA performed on leafminers identified a relatively small extent of differences within the same site from one year to the other. The opposite was observed for parasitoids, which were characterized by lower differences of the Shannon-Weaver index and higher similarity among sites than agromyzids. The information obtained from the PCA approach, showing significant variability within samples taken from the same site in the different years, agreed with the information obtained from the indices. In conclusion, many agromyzid species seem to be closely related to a particular site probably owing to high density of their suitable host plants, whereas parasitoid species, in most cases very generalistic species, seem to be relatively independent from the local weed composition and species composition of agromyzid assemblages, and more affected by other factors.

The trend obtained by plotting the number of parasitoid species recovered from each plant against the total number of insects (i.e. available hosts; Figure 6) suggests that agromyzid total densities could be the crucial factor for the maintenance of abundant and diverse parasitoid communities on the sampled weeds. Nevertheless, also climatic and agronomic conditions are probably involved in the composition and richness of parasitoid communities. Similar degrees of variability among years have been reported in other studies carried out by sampling foliage infested by agromyzids (Schuster et al., 1991; Valladares and Salvo, 2001), as well as in a survey by Malaise traps of *C. fuscula* and its parasitoids (Hågvar et al., 1998). Results from these studies indicate that in faunistic studies on parasitoids or in measuring their biodiversity, it is necessary to carry out sampling over an adequate period. In the present study, the number of parasitoid species found at each site was not correlated to the number of parasitoid individuals sampled (r = 0.26, P = 0.612, Spearman test) (Figure 9). This indicates that we probably came close to completely sampling the parasitoid fauna attacking agromyzids that colonise weeds. Therefore, a two-year sampling period seems to be adequate to collect a representative sample of the parasitoids in the studied areas.

Although indices of parasitoid biodiversity pointed out high overall levels of diversity at all the sites, some fluctuations in index values were detected from one year to the other within the same site. These fluctuations may be related to different ecological infrastructure conditions and pest management strategies that characterize each site. The smallest range of index variations from one year to the other was observed for site 3, which also showed the highest values of Shannon-Weaver and Simpson indices in both years. The complexity of ecological infrastructures, the highest connectivity, and the lack of chemical sprays characterizing site 3 were probably involved. On the contrary, the parasitoid assemblages in

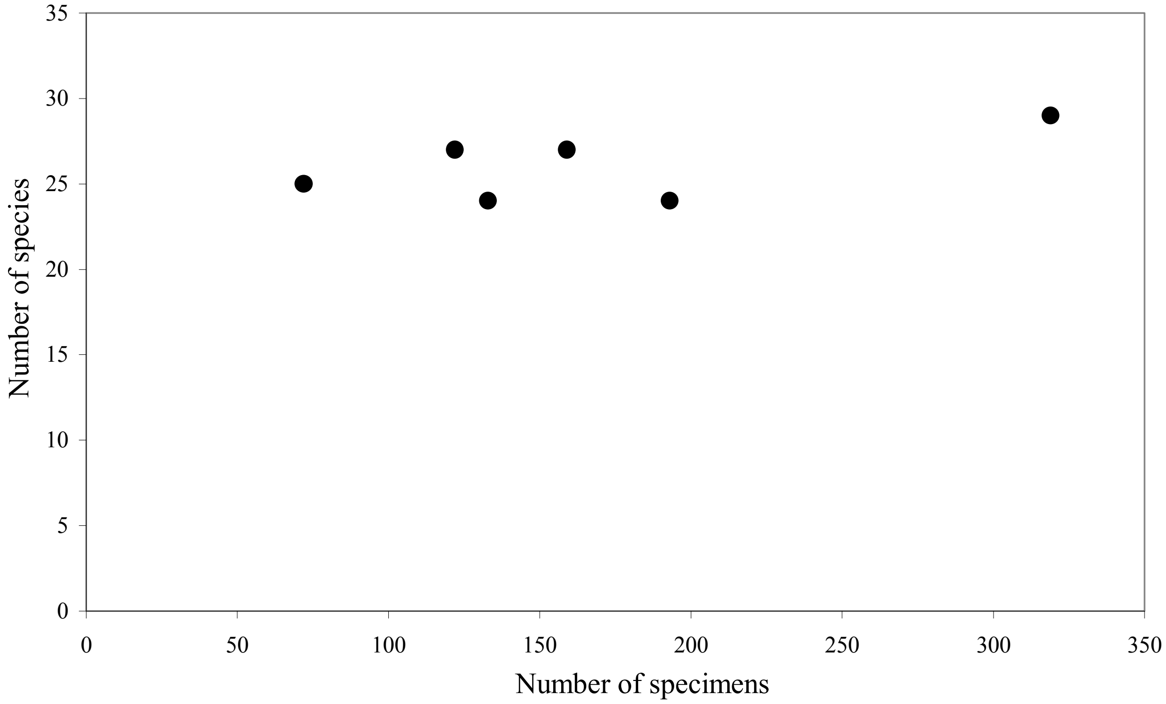

Figure 9. Species richness as function of sampled specimens.

site 1 and 2 showed higher levels of fluctuation which were probably related to the simplification of agroecosystems and to their intrinsic instability. At site 2, the lower index values for 1999 when compared to 1998, may point at a possible impoverishment of the parasitoid community from one year to the other. In contrast, at site 1 the increment of species richness, of total individuals sampled, and of both index values probably mirror an expansion of parasitoid communities from the first to the second year of sampling.

In our study, only two leafminers emerged from alfalfa leaves: *A. frontella* and *L. congesta*. Both species are restricted to Fabaceae (Spencer 1990) and have no economic importance in Europe. On the contrary, 10 parasitoid species, including *D. isaea* and *N. formosa*, were reared from alfalfa. For these reasons alfalfa, albeit harbouring only 3% of total wasps reared, could indeed be used as nursery plant for augmentation of agromyzid parasitoids. Moreover, several studies demonstrated the importance of alfalfa in providing resources for many beneficials (e.g. Tremblay and Pennacchio, 1988; Hodek and Honek, 1996).

Our study illustrates that weeds are crucial reservoirs of parasitoid and leafminer species. Interestingly, only few species of common and widespread wild plants that support high-density agromyzid populations appear to be relevant for the maintenance of both high numbers and species rich parasitoid assemblages. The parasitoid fauna sampled in this study included several potential biological control agents of agromyzid pests (i.e. polyphagous *Liriomyza* spp.) infesting open-field vegetable crops. The preservation and the proper management of native weeds in uncultivated marginal areas nearby crops could be an effective tool for the conservation and the augmentation of natural populations of agromyzid parasitoids. An important finding is also that the agromyzid species reared from these wild plants have negligible economic relevance in open field horticulture in Italy, and, therefore, the possibility that these weeds could become major sources of leafminer infestations seems to be unlikely. Nevertheless, other data are still required, for example to determine the impact of dominant parasitoid species in crop contexts and the extent of migration of both agromyzids and parasitoids between weeds and crop plants. In addition, the management of most of the sampled weed species implies also agronomic concerns that should be carefully considered in evaluating their preservation. Our studies focused on tritrophic interactions among weeds-leafminers-parasitoids on a small scale (a farm), but it is important to understand these dynamics also on a larger scale in a landscape context.

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Chapter 5

Spatial patterns and sampling plan for *Liriomyza huidobrensis* (Blanchard) (Diptera: Agromyzidae) and their parasitoids on lettuce

Abstract

Field experiments were carried out in 2000 and 2001 in Northern Italy, with the aim of developing a composite sampling strategy for estimating populations of *Liriomyza huidobrensis* (Blanchard) larvae and mines on lettuce. Larval parasitoid populations were also sampled in order to estimate the contribution of these beneficials to pest control. Covariance analysis and parallelism test indicated that there were no significant differences in the coefficient of Taylor's power law between treatments (untreated *vs* treated) and between seasons (2000 *vs* 2001) for both pest and parasitoid stages. The slope of each regression was significantly >1 for *L. huidobrensis* mines and larvae, and endoparasitoid and ectoparasitoid larvae, indicating a clumped distribution of both pest and parasitoids. Constant precision level stoplines for mines and larvae of *L. huidobrensis* and for endoparasitoid and ectoparasitoid larvae were calculated, using the common *a* and *b* derived from Taylor's power law. Wilson and Room binomial sampling was used to estimate the mean number of *L. huidobrensis* mines or live larvae from the ratio of leaves with mines. In this way it is possible to estimate the mean density of *L. huidobrensis* by counting the leaves with mines, an index parameter easy to obtain in field sampling. Validation of the presence-absence sampling plan using field data collected in the 2002 and 2003 seasons, showed that the Wilson and Room model fits very well the empirical data. Statistical analysis does not show any significant difference between observed and predicted data.

Introduction

The development of a management program to control *Liriomyza huidobrensis* (Blanchard) depends on the sampling methods that are suitable for rapid decision-making processes. Classical sequential sampling plans have been developed in the USA for *Liriomyza* larvae (Jones and Parrella, 1986; Heinz and Chaney, 1995). However, as suggested by Jones and Parrella (1986) and Heinz and Chaney (1995), these sampling plans are based on predetermined damage thresholds that may vary according to environmental and agroeconomic conditions. Like the findings reported by these authors for celery in the USA, tolerance to *L. huidobrensis* larvae on lettuce in Northern Italy is not based on a physiologically defined action threshold, but is based on each grower's assessment of the aesthetic quality of the crop within the context of the market conditions. In this case the development of a sequential sampling plan that estimates the mean density of a population relative to a predetermined level of precision could be a practical solution for monitoring *L. huidobrensis* larvae and mines on lettuce. This

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sampling plan must also offer an estimate of the density of leafminer parasitoid populations by the analysis of a damage parameter that is easy to determine in field (i.e. the ratio of leaves with mines), thus giving a preliminary evaluation of the efficacy of the biological control.

Our aim was to develop a composite sampling strategy for estimating *L. huidobrensis* larval and mine populations on lettuce, that also takes into account the possibility to sample the larval parasitoid populations in order to estimate the contribution of these beneficials to pest control.

Materials and Methods

Field experiments were carried out in the summer of 2000 and 2001 on two farms near Bologna, Northern Italy. Four transplants of lettuce (cultivar 'Trocadero') were sampled. The dates of transplant were: 10 July and 22 August 2000, 26 June and 14 August 2001. For each transplant two plots (each 196 m^2, 14 by 14 m) were delimited, corresponding to the following treatments: (1) untreated (biological); and (2) treated (chemical). The biological plots were left untreated and no leafminer parasitoids were released. The chemical plots were sprayed twice with cyromazine (Trigard 75 WP Novartis).

Once a week 50 basal leaves (2 leaves per plant) randomly selected were collected from each plot for the four or five weeks, depending on the season, subsequent to the transplanting. Leaves were placed in an ice box and taken to the laboratory where they were examined using a stereomicroscope with transmitted light. Agromyzid feeding tunnels were opened and all pupae and larvae were dissected. The number of mines, healthy leafminer instars, dead agromyzid larvae, and larval and pupal stages of endoparasitoids and ectoparasitoids were recorded.

Data analysis

The mean and the sampling variance of mines, live larvae, total larvae, endoparasitoid larvae and ectoparasitoid larvae, were calculated for each sampling date. Taylor's power law ($s^2 = am^b$) (Taylor, 1961; 1984), which describes the correlation between means and sampling variance, was used to study the spatial distribution of mines and larvae of *L. huidobrensis* and parasitoid larvae. Taylor's parameters (*a* and *b*) were estimated by regression of log (s^2) on log (m), where the intercept *a* is dependent on sampling method and the slope (*b*) is defined as index of aggregation; as such the latter is a constant per species and it varies continuously from a regular distribution for $b \rightarrow 0$, to random for $b = 1$, to clumped for $b > 1$ (Taylor, 1961).

Analysis of covariance was used to compare the parameters of Taylor's power law between treatments (untreated *vs* treated plot) and between the years (2000 *vs* 2001 season), with the aim of determining whether a common regression could be used to describe the spatial distribution of mines and larvae of *L. huidobrensis* and larvae of parasitoids.

The results of Taylor's analysis were also used to evaluate constant precision-level sampling plans for mines and live larvae of *L. huidobrensis* and endoparasitoid and ectoparasitoid larvae (Binns and Nyrop, 1992; Naranjo and Hutchison, 1997). The formula of Green (1970) was used to calculate stoplines for the sequential samples:

$$\mathrm{T}n = [\mathrm{d}^2/\mathrm{antilog}\ (a)]^{1/(b-2)}\ n^{(b-1)/(b-2)}, \qquad (1)$$

where Tn is the cumulative number of mines or larvae over n sample units (leaves), d is the fixed level of precision and *a* and *b* are from Taylor's regression.

The equation of Wilson and Room (1983) was utilized in an effort to develop the presence-absence sampling plan:

$$P(I) = 1- \exp\{-m\ [\ln (am^{(b-1)})(am^{(b-1)}-1)^{-1}]\}, \qquad (2)$$

where $P(I)$ is the proportion of sampling unit (leaves) with mines or live larvae of *L. huidobrensis* and m is the mean number of mines or larvae per leaf, and the constants a and b derives from Taylor's power law.

The regression model of Gerrard and Chiang (1970) was also used to relate the ratio of infested leaves (p) to the mean density of mines and larvae per leaf, and to relate the mean density of endoparasitoid and ectoparasitoid larvae with infested leaves:

$$\mathrm{Ln}\ (m) = \alpha + \beta \ln [- \ln (1-p)], \qquad (3)$$

where α and β are constants.

Validation test of the presence-absence sampling plan

In 2002 and 2003, eight plots (four plots each year) were established in lettuce fields (cultivar 'Trocadero') in two organic farms located in the province of Bologna (northern Italy). The plots were not sprayed with chemicals and no leafminer parasitoids were released. Each plot of ca. 70 m^2 was sampled by a randomized selection of 100 basal leaves (2 leaves per plant) on a weekly basis. Field samples were taken from late June to early October. Leaves were examined as described above. The validation of the Wilson and Room (1983) model was performed by comparing the observed frequencies (from the sets of data collected in 2002 and in 2003) with those predicted by equation 2, calculated using the coefficients of Taylor's power law from data collected in 2000 and 2001. The comparison between observed and predicted frequencies was carried out by Chi-square goodness of fit test (Zar, 1984).

Results and Discussion

The covariance analysis and the parallelism test indicated that there were no significant differences in the coefficient of Taylor's power law between treatments (untreated *vs* treated) and between seasons (2000 *vs* 2001) for both pest and parasitoid stages (Table 1). For these reasons common regressions were used to predict the variance-to-mean relationships (Table 2). The slope of each regression was significantly >1 for *L. huidobrensis* leaf mines and larvae, and endoparasitoid and ectoparasitoid larvae (leaf mines: t = 23.37, df = 35, $P < 0.001$; live larvae: t =34.05, df = 35, $P < 0.001$; total larvae: t = 31.36, df = 35, $P < 0.001$; endoparasitoid larvae: t = 43.16, df = 26, $P < 0.001$; ectoparasitoid larvae: t = 20.70, df = 15, $P < 0.001$), indicating a clumped distribution of both pest and parasitoids.

Heinz and Chaney (1995) reported log a values of 0.233 and 0.208, and b values of 1.257 and 1.187, for live larvae and leaf mines of *L. huidobrensis* on celery. Comparing the values of the coefficients of the present study with those reported by Heinz and Chaney (1995), some slight differences can be detected in the intercepts and, in to lesser extent, in the aggregation of live larvae. In particular, *L. huidobrensis* on celery showed a more aggregated pattern in comparison with data of the present study. This could be due to the different architecture of the crops and the different size of the plots. Jones and Parrella (1986) found for *Liriomyza trifolii* (Burgess) infesting chrysanthemums, log a values of 0.750 and b value of 1.19 for live larvae, and log a value of 0.784 and b value of 1.15 for leaf mines. Although Taylor's coefficients among *Liriomyza* species and crops show similar values, we suggest a specific sampling plan for each species-crop system, because some differences in these parameters have been detected.

Table 1. Comparison of the coefficients from Taylor's power law between management strategies and seasons.

Parameters	Treatments	ANCOVA		Parallelism test	
		$F_{(df)}$	P	$F_{(df)}$	P
Mines/leaf	Untreated *vs* Treated	$0.16_{(1,34)}$	0.68	$0.044_{(1,33)}$	0.83
	2000 *vs* 2001	$0.04_{(1,34)}$	0.841	$0.041_{(1,33)}$	0.839
Total larvae /leaf	Untreated *vs* Treated	$1.36_{(1,34)}$	0.25	$0.42_{(1,33)}$	0.51
	2000 *vs* 2001	$1.36_{(1,34)}$	0.250	$0.427_{(1,33)}$	0.51
Live larvae/leaf	Untreated *vs* Treated	$1.97_{(1,34)}$	0.16	$0.305_{(1,33)}$	0.58
	2000 *vs* 2001	$0.123_{(1,34)}$	0.727	$0.685_{(1,33)}$	0.413
Ectoparasitoid larvae/leaf	Untreated *vs* Treated	$1.49_{(1,14)}$	0.23	$0.03_{(1,13)}$	0.86
	2000 *vs* 2001	$0.205_{(1,14)}$	0.656	$0.909_{(1,13)}$	0.357
Endoparasitoid larvae/leaf	Untreated *vs* Treated	$0.26_{(1,25)}$	0.59	$0.36_{(1,24)}$	0.54
	2000 *vs* 2001	$1.28_{(1,25)}$	0.266	$0.008_{(1,24)}$	0.92

Table 2. Coefficients from the common Taylor's power law calculated from mines, total larvae and live larvae of *L. huidobrensis*, and endoparasitoid and ectoparasitoid larvae.

Parameters	Ln *a* (SE)	*b* (SE)	r^2	P	*n*
Mines/leaf	0.505 (0.056)	1.108 (0.042)	0.95	<0.001	37
Total larvae/leaf	0.54 (0.052)	1.12 (0.035)	0.96	<0.001	37
Live larvae/leaf	0.48 (0.055)	1.12 (0.03)	0.96	<0.001	37
Endoparasitoid larvae/leaf	0.39 (0.0046)	1.15 (0.026)	0.98	<0.001	28
Ectoparasitoid larvae/leaf	0.75 (0.16)	1.21 (0.058)	0.96	<0.001	17

In the present study, the aggregation index of endoparasitoids shows almost identical values in comparison with those of *L. huidobrensis*. Feng et al. (1993) in a study on *Sitobion avenae* (F.) and *Aphidius ervi* Haliday spatial distribution, found that the *b* value for the aphid species was significantly greater than that of the parasitoid. Comparing the values of *b* of endoparasitoids (b = 1.15) with ectoparasitoids aggregation indices (b = 1.21) of our study, we can hypothesize that the searching capacity of endoparasitoids might be relatively higher for the lower value of the aggregation index.. A strong searching behavior of parasitoids may distribute them over the host population, leading to a less aggregated distribution. This is a preliminary conclusion because of the the lack of data about the searching efficiency of leafminers parasitoids. Moreover, a complex of species is included in the category of endo- and ectoparasitoids, although there is a predominance of *Dacnusa sibirica* (Telenga) among endoparasitoids, and *Diglyphus isaea* (Walker) among ectoparasitoids in North Italy (Burgio et al., 2000; Lanzoni et al., 2003).

Constant precision level stoplines for mines and live larvae of *L. huidobrensis* (Figure 1) and for endo- and ectoparasitoid larvae (Figure 2), were calculated with the Green (1970) method, using the common *a* and *b* derived from Taylor's power law. The Green sampling method requires that leaf samples have to be taken sequentially until the cumulative number of live larvae, leaf mines and parasitoid larvae exceed stopline values for the number of samples collected. The mean density can be estimated as a quotient of the cumulative number of larvae or mines divided by the number of samples.

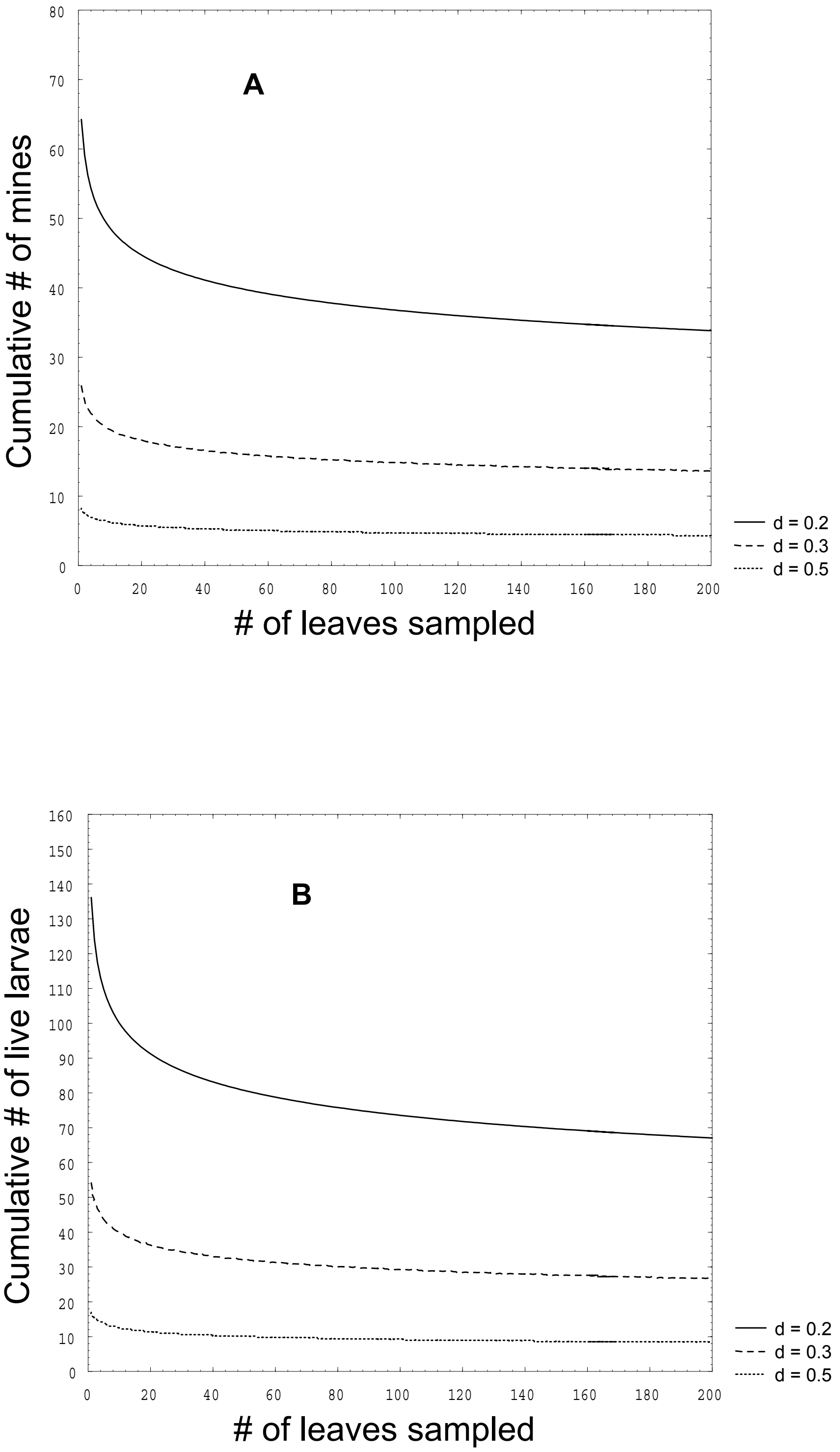

Figure 1. Stop lines calculated for *L. huidobrensis* mines (A) and live larvae (B) at three different precision levels.

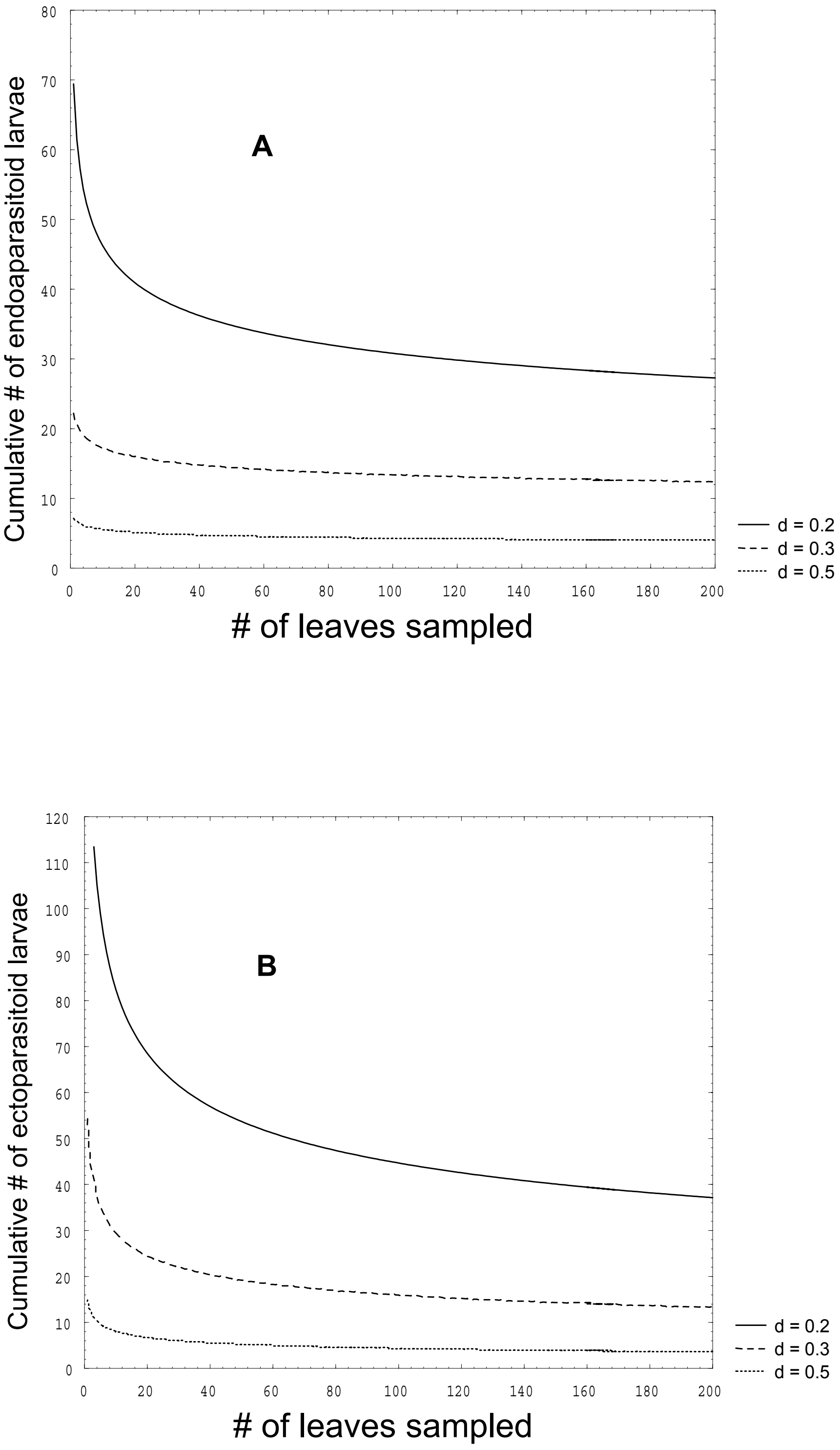

Figure 2. Stop lines calculated for endo-parasitoid larvae (A) and ecto-parasitoid larvae (B) at three different precision levels.

The mines seem to be the most practical parameter to use for the sampling of *L. huidobrensis* populations on lettuce, because it is easy to monitor in the field. Moreover, the mean number of mines per leaf is statistically strongly correlated with the mean number of live larvae per leaf ($y = 0.226 + 1.091\ x$, $r = 0.96$, $P < 0.001$; Figure 3). This evidence supports that mines can be utilized as infestation index. Our data demonstrate that it is not necessary to sample the larvae of the pest because this stage is very time-consuming to sample and it is not easy to detect in field. For example, applying this criterion, and considering a precision level of $d = 0.2$, the sampling is stopped when, after 50 leaves examined, the cumulative number of mines sampled exceeds the value of 40 or, after 100 leaves examined, the cumulative number exceed 36 (Figure 1). In the first case the mean density of *L. huidobrensis* mines is 0.8, in the second case it is 0.36. Figure 2 provides the information for sampling the parasitoid populations. In this case the leaves must be collected sequentially, taken to the laboratory and dissected under a microscope to count the parasitoid larvae. The sequential curves for *L. huidobrensis* mines are overlapping with those of endoparasitoid larvae and for this reason the same number of leaves can be taken to sample these stages. However, sampling ectoparasitoid larvae requires a higher number of leaves in comparison with the sampling of *L. huidobrensis* mines.

The coefficients of Taylor's power law were put in the mathematical model of the Wilson and Room (1983) equation to develop a presence-absence sampling plan, i.e. to estimate the mean number of *L. huidobrensis* mines or live larvae from the ratio of leaves with mines. In this way it is possible to estimate the mean density of *L. huidobrensis* by counting the leaves with mines, which is a parameter easy to obtain during field sampling.

Validation of the presence-absence sampling plan using field data collected in 2002 and 2003 seasons (Figure 4) shows that the Wilson and Room (1983) model fits empirical data

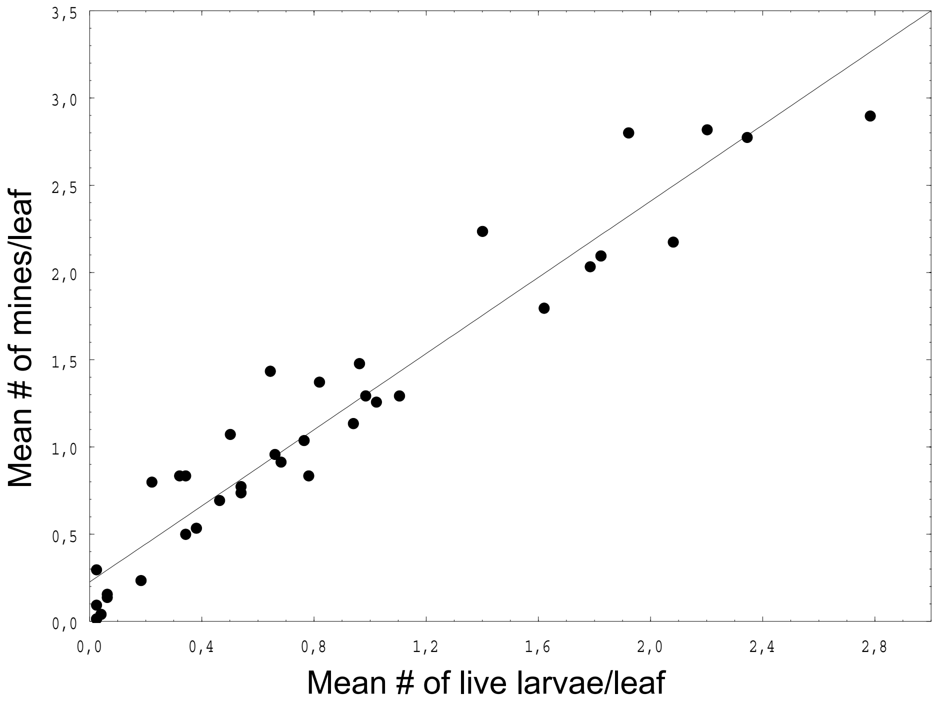

Figure 3. Linear correlation between the mean number of mines per leaf and the mean number of live larvae per leaf.

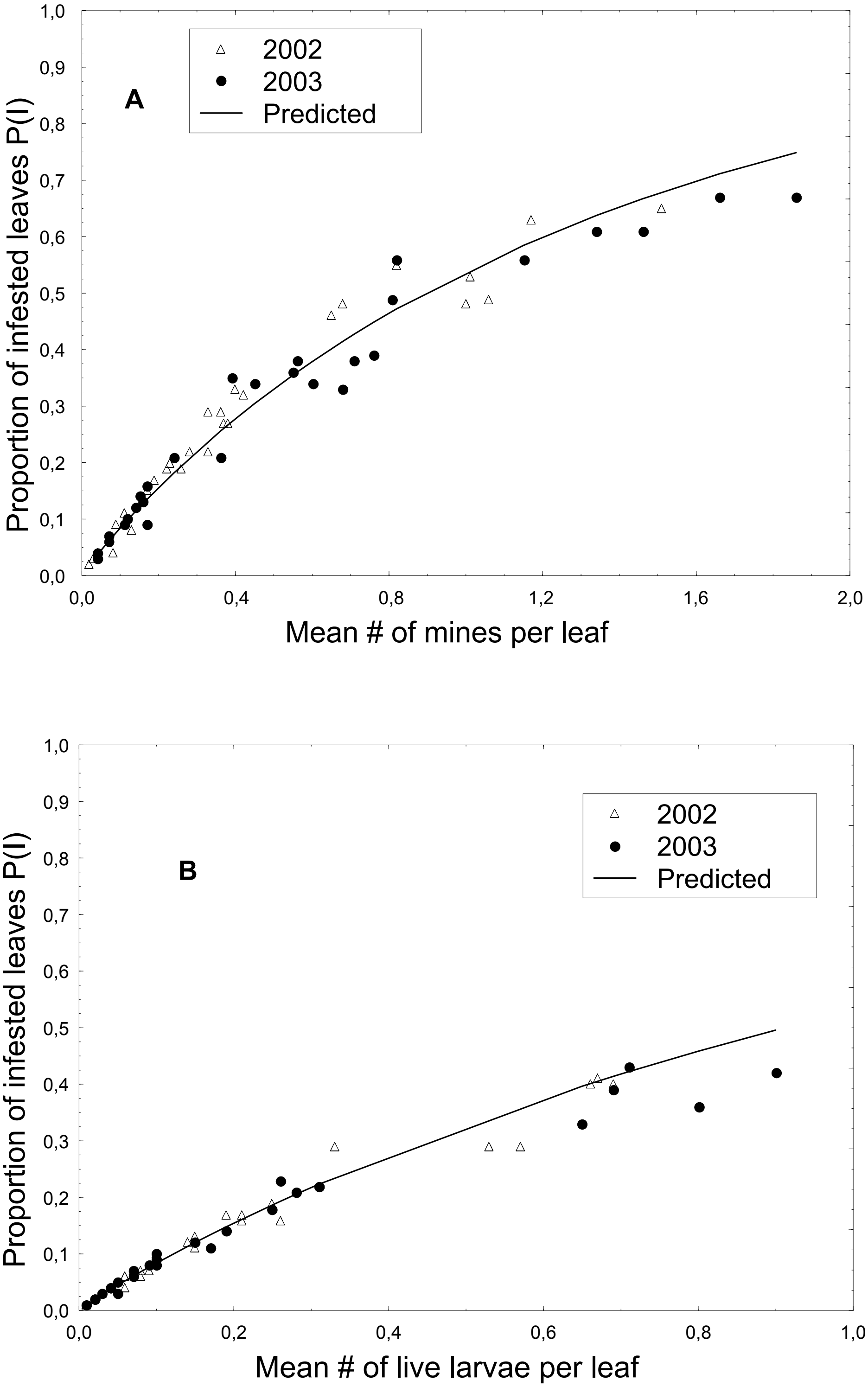

Figure 4. Relationship between the proportion of leaves with mines *P*(*I*) and the mean number of mines per leaf (A) or mean number of live larvae (B) of *L. huidobrensis*. The solid lines (—) represent predicted values from the model of Wilson and Room calculated using data collected during the 2000 and 2001 growing seasons. Triangles (Δ) represent validation data obtained during the 2002 growing season, and dots (●) validation data obtained during the 2003 growing season.

very well. Statistical analysis does not show any significant difference between observed and predicted data (2002: $\chi^2_{\text{mines}} = 0.118$, df = 29, $P > 0.999$; $\chi^2_{\text{live larvae}} = 0.0059$, df = 29, $P > 0.999$; 2003: $\chi^2_{\text{mines}} = 0.135$, df = 27, $P > 0.999$; $\chi^2_{\text{live larvae}} = 0.07$, df = 27, $P > 0.999$). Heinz and Chaney (1995) reported for *L. huidobrensis* infesting celery that validation tests of the presence-absence sampling plan yielded predicted frequencies of infested petioles significantly greater than the frequencies of petioles infested with larvae, showing a lack of fit between predicted and expected frequencies. Jones and Parrella (1986) reported no significant differences between predicted and observed frequencies in the case of *L. trifolii* infesting greenhouse-grown cut chrysanthemums.

Jones and Parrella (1986) and Heinz and Chaney (1995) discussed the relative merits of sample size based on reliability against a fixed sample size for their ability to predict the sample mean. The use of a 100-petiole sample size within the context of a presence-absence sampling plan as recommended by Jones and Parrella (1986) is favored over the sample size estimate by Karandino's (1976) formula. Sampling plans utilizing fixed sample sizes are favored because the sampling size is independent of *P(I)* and because they provide increased precision of estimates as *P(I)* increases. Heinz and Chaney (1995) reported that implementation of a sequential sampling plan for *L. huidobrensis* larvae with a 0.25 level of precision and with a possible maximum sample size of 100 petioles should greatly reduce the amount of labor necessary to achieve accurate estimates of population densities and to facilitate the use of action thresholds based upon these estimates.

To estimate the mean density of parasitoid larvae by a binomial sampling, it is convenient to take a sample, to calculate the ratio of leaves damaged or with mines, and to obtain an estimate of the parasitoid population. This information is essential to evaluate the efficacy of biological control during the crop season. In this case the ratio of infested leaves does not necessarily correspond to leaves with parasitoid larvae. For this reason it is necessary to collect a sample of leaves, to open the mines and to check the presence of parasitoids, a procedure which is very difficult to carry out in field and which needs highly skilled personnel. This is why it is not correct to put the Taylor's coefficient of larval parasitoids in the Wilson and Room equation: there is a lack of correspondence between leaves with mines and leaves with larval parasitoids. Therefore, to obtain a binomial estimate of larval parasitoid populations from infested leaves, the statistical model of Gerrard and Chiang (1970) was utilized. With this empirical model, the mean population density of larval parasitoids is estimated by the ratio of infested leaves, a parameter which is easy to determine in the field. In any case, for the lack of evidence of a constant density dependent relationship between the host and it's related parasitoid complex, this statistical correlation cannot rigorously be used in agro-ecological conditions that are very different from those reported in this study. Moreover, the field parasitism rate incorporates the effect of many parasitoid species and for these reasons our statistical correlation can be successfully applied only on a local scale. As shown in Table 3 there is a significant correlation between leaves with mines and the mean number of larval endoparasitoids ($r = 0.77$, $P < 0.001$; Figure 5). The correlation between the ratio of infested leaves and the mean number of larval ectoparasitoids was not significant ($r = 0.32$, $P = 0,21$) (Table 3). This can be due to the low number of data or to the lack of a functional relation between the density of ectoparasitoid populations and infested leaves. The coefficients of the Gerrard and Chiang (1970) statistical model calculated for binomial sampling of *L. huidobrensis* stages are reported in Table 3. All the relations are significant, with the determination coefficient ranging from 0.90 to 0.98. The Gerrard and Chiang binomial sampling information is presented in Figure 5.

Table 3. Parameters of Gerrard and Chiang (1970) equation, (ln (m) = $\alpha + \beta$ ln [-ln(1 – p)], for binomial estimation of pest and parasitoid populations. Standard Errors are in brackets. m = mean number specimens/leaf, p = ratio leaf with insects.

Variable	α	β	*r*	P
Mines/leaf	0.36 (0.04)	1.036 (0.03)	0.98	<0.001
Larvae (total)/leaf	0.13 (0.08)	1.039 (0.05)	0.98	<0.001
Live larve/leaf	-0.08 (0.11)	1.084 (0.08)	0.90	<0.001
Endoparasitoid larvae/leaf	-0.94 (0.15)	1.36 (0.22)	0.77	<0.001
Ectoparasitoid larvae/leaf	-2.79 (0.2)	0.59 (0.45)	0.32	0.21

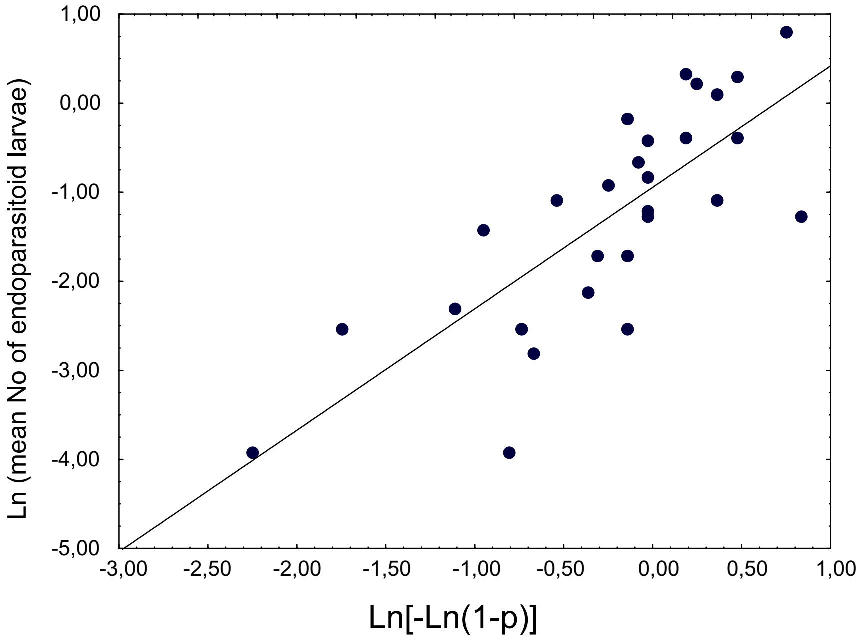

Figure 5. Binomial sampling regression as calculated by the Gerrard and Chiang (1970) model for estimating endoparasitoid larvae per leaf. The parameters of the regression are shown in Table 3.

The Gerrard and Chiang binomial sampling can be utilized in combination with the sequential sampling to estimate the mean number of endoparasitoid larvae by means of the ratio of leaves infested by the pest, calculated by the sample. The possibility of estimating the beneficial population by this easy method can facilitate the field sampling and the IPM strategies for *L. huidobrensis*, because the estimation of the parasitoid populations by the Green method is difficult to obtain, requiring the collection of leaves and the dissection of the mines in the laboratory. The Gerrard and Chiang method offers a rapid and practical method to estimate the endoparasitoid populations, although the coefficient correlation (r = 0.77) is lower than that calculated for pest stages (r = 0.90 for live larvae; r = 0.98 for mines and total larvae). However, the binomial sampling of endoparasitic larvae, including information on the activity of the parasitoids, gives a more complete protocol in the integrated management of *L. huidobrensis*.

An integrated sampling plan that includes the monitoring of *L. huidobrensis* larvae and parasitoid larvae is crucial to plan a rational control of the pest based on the real population densities in the crop. Moreover, a sampling protocol taking into account pest and beneficial populations is important in biological control of leafminers to determine the number of releases of a parasitoid species (i.e. *D. isae* and/or *D. sibirica*) and the number of specimens to release. This sampling could also be effective in advanced IPM programmes to evaluate the efficacy of chemical sprays and the selection of resistant strains.

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Chapter 6

Role of annual flowering plant mixture on parasitism of agromyzid leafminers (Diptera: Agromyzidae) on lettuce

Abstract

The aim of the present study was to test the efficacy of flowering plant strips to enhance the performance of parasitoids in conservation biological control of *Liriomyza huidobrensis* on lettuce. Field experiments were carried out in 2002 and 2003 at two organic farms located in the province of Bologna in northern Italy. The development of leafminer populations and their parasitoids on lettuce plots surrounded by flowering plants was compared with a lettuce plots surrounded by bare soil. In the 2003 season, parasitism was enhanced by the flowering plants, while in 2002 the difference between the parasitism in lettuce surrounded with flowering plants and lettuce surrounded with bare soil was not significant. In both years, parasitism by endoparasitoids was higher than that of ectoparasitoids. Overall, flowering plants showed a more pronounced positive effect on parasitism by ectoparasitoids than endoparasitoids, mainly represented by *Dyglyphus isaea*. The increase in parasitism in lettuce plots surrounded by flowering field strips was higher in the first week after transplanting than in later weeks. However, the augmentation of parasitoids and parasitism did not result in a significant reduction of the agromyzid pest when compared with fields surrounded by bare soil, but this may have been the result of a high level of parasitism that also occurred in the control fields.

Introduction

There is a number of reasons which makes biological control against the leafminers, including *Liriomyza huidobrensis* (Blanchard), more effective than chemical control. First of all, insecticides are poorly effective against leafminer larvae that are living inside the leaf. Secondly, leafminers rapidly select resistance against pesticides. Further, overall data from agricultural ecosystems suggest that parasitoids are often responsible for a significant level of leafminer mortality if pesticides are not applied (e.g. Johnson and Hara, 1987; Weintraub and Horowitz, 1998). The role of parasitoids in conservation biological control of leafminers like *L. huidobrensis* has been proved in many field trials (e.g. Murphy and LaSalle, 1999). In this context the preservation and the rational management of weeds within field margins is a crucial tool to enhance populations of biological control agents of agromyzids and to conserve rare parasitic wasp species (Burgio et al., 2004). In northern Italy, *L. huidobrensis* can be a serious pest in open field lettuce (Burgio et al., 2005). Empirical data suggest that if chemical sprays against leafminers infesting lettuce are suspended, biological control by parasitoids can be effective to limit the pest populations (Lanzoni et al., 2000).

In some annual cropping systems, natural biological control may be too late because natural enemies colonize the target crop when pest populations have already built up (van Lenteren, 1980). Thus, situations need to be created where these natural enemies can survive and multiply so that they can invade the crop early and in sufficient numbers. An important element of conservation biological control is the management of natural enemies at times when hosts are not present in the crop (Bukovinszky, 2004). Several studies have already pointed out that the lack of food in agricultural crops can represent a potential impediment to the successful functioning of beneficial insects (e.g. Winkler, 2005). To provide this food for beneficial insects, the establishment of flowering field edges to benefit parasitoids has been suggested and currently a number of seed mixtures are commercially available (Landis et al., 2000; Winkler, 2005). A detailed analysis of plant-provided food for carnivorous insects, including insect parasitoids, is given by Wäckers et al. (2005). Floral nectars can potentially improve biological control by parasitoids and several studies have demonstrated that non-crop resources enhance one or more components of natural enemy fitness (e.g. Gurr et al., 2005). However, few studies have explored the effects of floral resources on natural enemies in the field and tested the mechanisms underlying these effects (Gurr et al., 2005; Winkler et al., 2005). Within landscape management approaches, the choice of a flowering mixture is a complex and delicate process. Ideally, flowering field edges should consist of "selective" plants that mainly promote the performance of natural enemies without supporting pest species (Winkler, 2005; Wäckers et al., 2005; Winkler et al., 2005; 2006).

In this chapter I describe a rather special case of the potential use of field edges in lettuce, a crop which production is characterised by a rapid cycle of only about 6 weeks. So, in order to realise effective conservation biological control in such a short cropping cycle, an efficient synchronization between the presence of the parasitoids with that of the leafminer larvae is essential. In this context, an approach with flowering field margins seemed attractive, as these plants would provide food for the natural enemies which lettuce does not supply. The aim of the present study was to test the efficacy of flowering field edges to enhance the performance of parasitoids in the conservation biological control of *L. huidobrensis* on lettuce.

Materials and Methods

Field experiments were carried out in 2002 and 2003 at two organic farms located in the province of Bologna in northern Italy. Four transplants of lettuce (cultivar 'Trocadero') were sampled. For each transplant, two plots of 8 by 8 m separated from each other by 25 m of bare ground were delimited. The development of leafminer populations and their parasitoids on lettuce plots surrounded by flowering plants was compared with a lettuce plots surrounded by bare soil. A seed mixture of flowering plant species was sown around the perimeter of the treatment plots, thus forming a one-meter wide edge. Lettuce seedlings were transplanted in both treatments when in the flowering field edge plot at least 80% of the plants were in bloom. Lettuce was transplanted on 28 May, 3 June, 17 June, and 2 September 2002, and 4 July, 11 July, 13 August, and 27 August 2003. The plots were unsprayed and no leafminer parasitoids were released. The flowering plant seed mixture composition (Table 1) was determined according to literature data (Bugg and Waddington, 1994; Delucchi, 1997; Jervis et al., 1993; Wäckers, 2001). Preliminary field tests have shown that the selected mixture was suitable for the lettuce crop system and presented no negative effects.

A sample of 100 basal leaves (2 leaves per plant) randomly selected was collected weekly from each plot from June to October. The samplings were carried out from the first to the fourth week after transplanting.

Leaves were placed in ice chests and taken to the laboratory where they were examined using a stereomicroscope. Agromyzid feeding tunnels were opened and all larvae and pupae were dissected. The number of leafminer stages (healthy, parasitized and dead), as well as the pre-imaginal stages of endoparasitoids and ectoparasitoids was recorded.

Table 1. Seed mixture composition of the flowering plant strips.

Flowering plant species	%
Phacelia tanacetifolia	45
Sinapis arvensis	15
Borago officinalis	10
Trifolium incarnatum	10
Trifolium alexandrinum	5
Trifolium pratense	5
Vicia faba	5
Vicia sativa	5

In order to find out which species of parasitoids had parasitized the leafminers, additional sampling was done in 2002. A sample of lettuce leaves infested by leafminers was collected from each plot, stored in ice bags and returned to laboratory. Foliage, previously categorized by date and treatment, was stored in Plexiglas cylindrical cages (Ø 9 cm, h, 18 cm) to rear parasitoids to adulthood. Leaves were hung to a wire, and each container was closed with fine gauze to increase air circulation and to reduce mould growth. Containers were stored in a climatic chamber at 25 ± 1 °C, 80 ± 10% RH, and LD 16:8 h photoperiod for 40 days. Once a week puparia, when pupation occurred outside the leaf, and adult wasps were removed from the containers. Leafminer puparia were placed in glass vials plugged with cotton and stored in the climatic chamber to check the emergence of adult larval/pupal parasitoids. Individuals were killed, dried and prepared for identification.

In order to quantify the economic damage caused by leafminers to the crop, the number of healthy, mined and punctured leaves were counted on 10 randomly selected lettuce heads from each plot during harvesting on 1, 8 and 22 July and 9 October of 2002.

Statistical analysis

Percentage of parasitism was calculated as the number of parasitized hosts divided by the number of parasitized hosts + number of healthy hosts + number of died hosts x 100.

Data were analyzed by a factorial analysis of variance (ANOVA) in a randomized block design, in order to assess whether flowering plants affected parameters like agromyzid density and percentage of parasitism. The main factors tested were: *treatments* (T) (lettuce with flowering plants-control) and *weeks after transplanting* (W) (week 1- week 2- week 3- week 4); *transplantings* (1-2-3-4) were considered as blocks. Percentages of parasitism were arcsine transformed before analysis.

Results and discussion

A total of 1998 pre-imaginal agromyzids was dissected, 941 of which were parasitized and 1231 parasitoid immature stages were found in these parasitized hosts. Endoparasitoids accounted for 1038 specimens, whereas ectoparasitoids accounted for 193 specimens.

In both years agromyzid densities did not show any difference between the two treatments (Table 2). In 2002 the difference between the total parasitism in lettuce with “flowering plants” and lettuce with “bare ground” (Figure 1) was not significant, but the P value (= 0.081) was close to the significance level (Table 2). In 2003 the total parasitism was enhanced by the flowering plants (Table 2; Figure 2). Overall, flowering plants showed a more pronounced positive effect on parasitism by ectoparasitoids than endoparasitoids. Ectoparasitoids were mainly represented by *Dyglyphus isaea* (Walker) (Figures 3 and 4). As a matter of fact, total parasitism by ectoparasitoids was significantly enhanced by the flowering plants strip in both years (Table 2, Figures 3, 4, 5 and 6). Contrarily, parasitism by endoparasitoids was not significantly increased by the flowering plants strips (Table 2; Figures 7, 8, 9 and 10). In both years and in both treatments, parasitism by endoparasitoids was generally higher than that of ectoparasitoids (Figures 11 and 12).

Table 2. P ANOVA of the leafminer density, total % parasitism and % parasitism by ecto- and endo-parasitoids. Percentages were transformed in arcsin $\sqrt{x}$ before analysis.

Source of variation	2002 Treatment (T)	2002 Week after Transplant (W)	2002 Transplant	2002 T x W	2003 Treatment (T)	2003 Week after Transplant (W)	2003 Transplant	2003 T x W
Agromyzid density	0.7607	**0.0093**	**0.00001**	0.9878	0.6659	0.0697	0.4916	0.1937
Total parasitism	0.0814	0.0815	**0.0002**	0.8560	**0.0042**	**0.0036**	0.4453	0.0601
Parasitism by endopar	0.3545	0.0954	**0.0001**	0.4787	0.3481	**0.0096**	0.5319	0.3234
Parasitism by ectopar	**0.0069**	0.1503	0.0668	0.3247	**0.0083**	0.6613	0.1796	0.5248
df=	1,20	3,20	3,20	3,20	1,19	3,19	3,19	3,19

Figure 1. Comparison of the % total parasitism in "flowering plants" and "bare soil" plots in 2002. Data pooled for all weeks. Same letters indicate P>0.05 from ANOVA (see table 2).

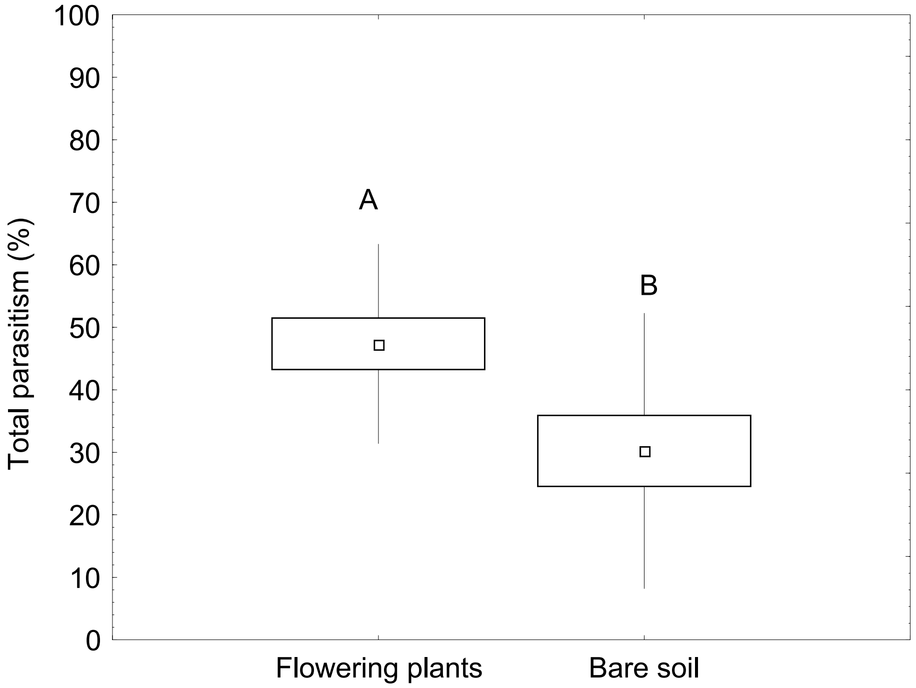

Figure 2. Comparison of the total parasitism (%) in "flowering plants" and "bare soil" plots in 2003 season. Different letters indicate P<0.01 from ANOVA (see Table 2).

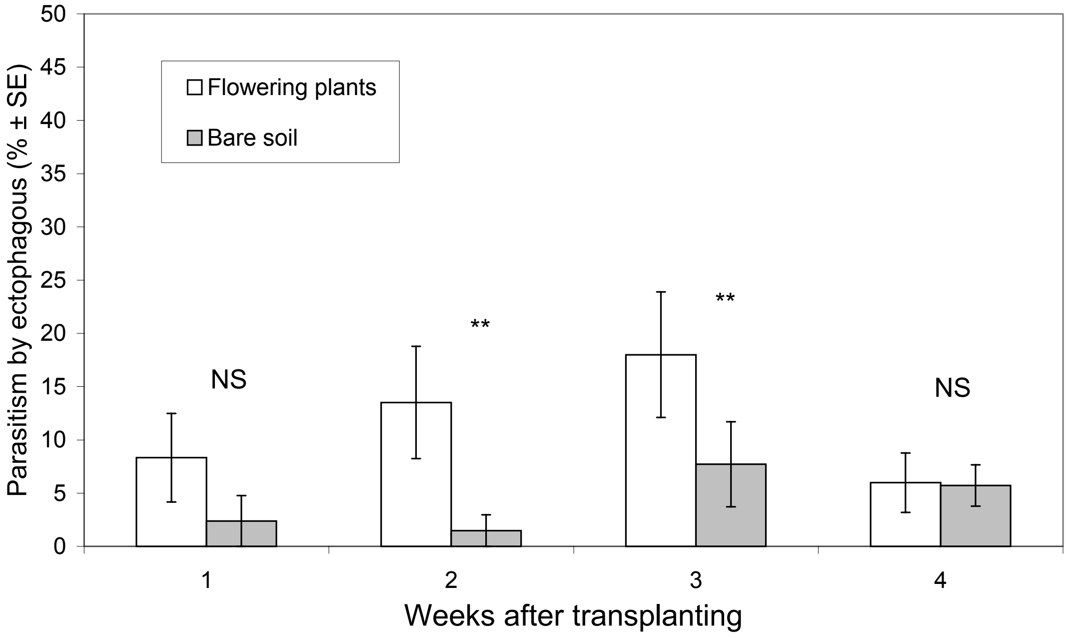

Figure 3. Percentage parasitism by ectoparasitoids in 2002 as function of the weeks after transplanting. Bars indicate standard error of the mean (SE). **: P< 0.01; NS: P>0.05 (chi-square test).

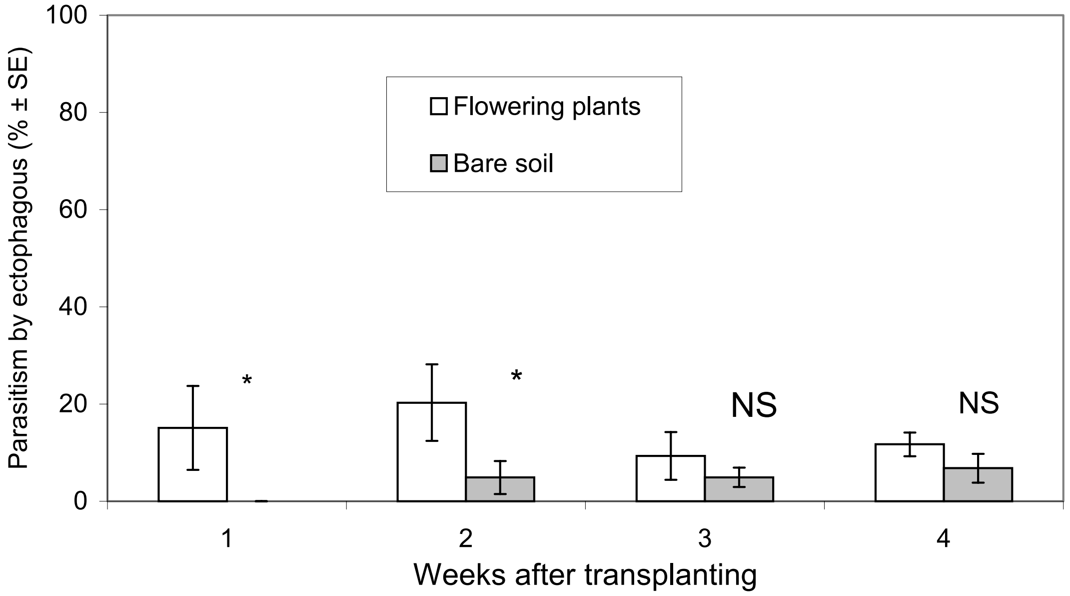

Figure 4. Percentage parasitism by ectoparasitoids in 2003 as function of the weeks after transplanting. Bars indicate standard error of the mean (SE). **: P< 0.01; NS: P>0.05 (chi-square test).

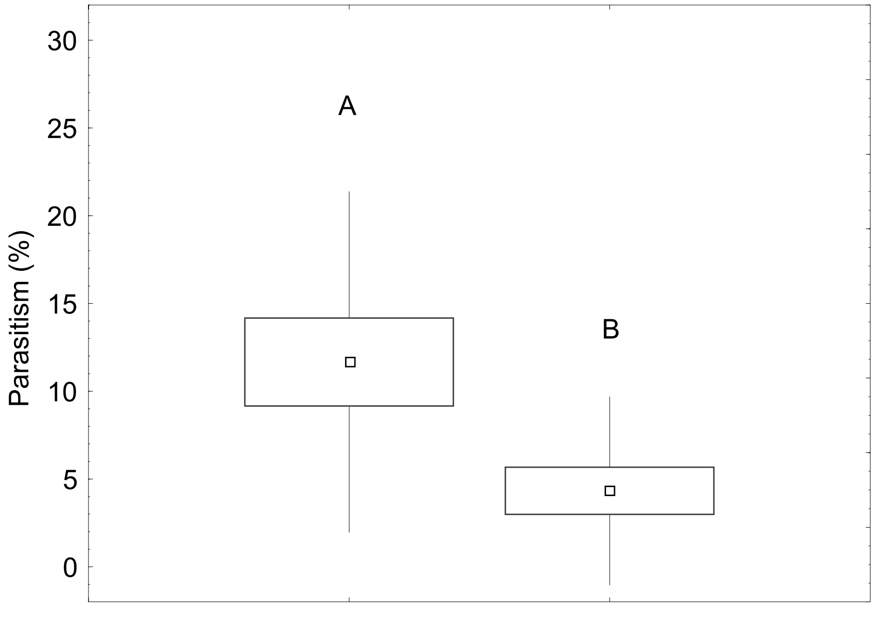

Figure 5. Comparison of the % parasitism by ectoparasitoids in “flowering plants” and “bare soil” plots in 2002. Different letters indicate P<0.01 from ANOVA (see Table 2).

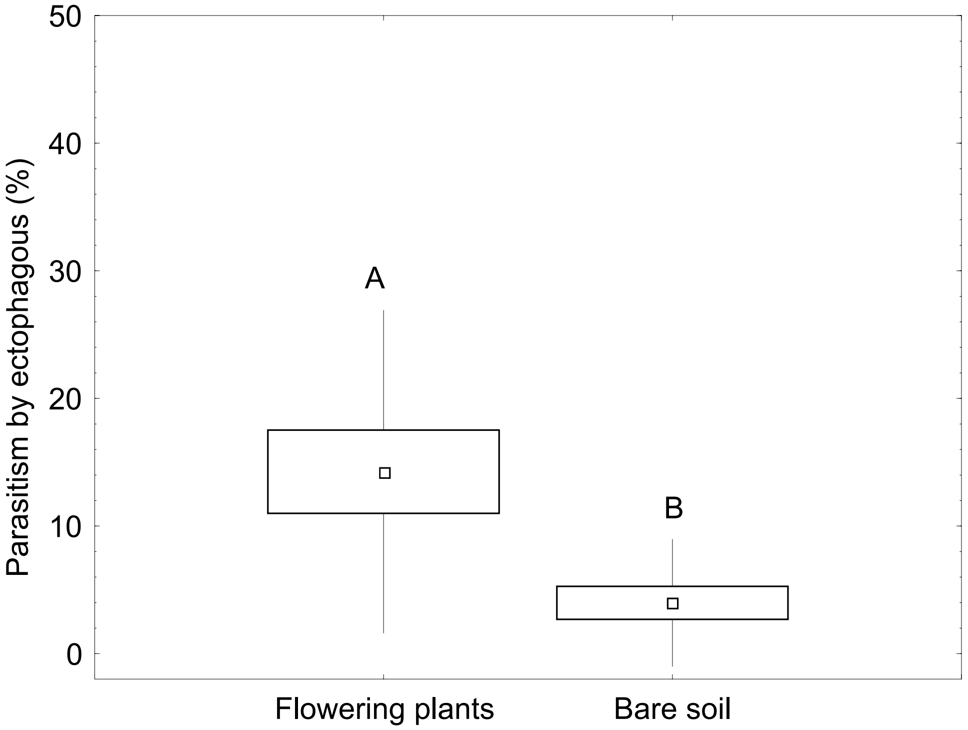

Figure 6. Comparison of the % parasitism by ectoparasitoids in "flowering plants" and "bare soil" plots in 2003. Data pooled for all weeks. Different letters indicate P<0.01 from ANOVA (see Table 2).

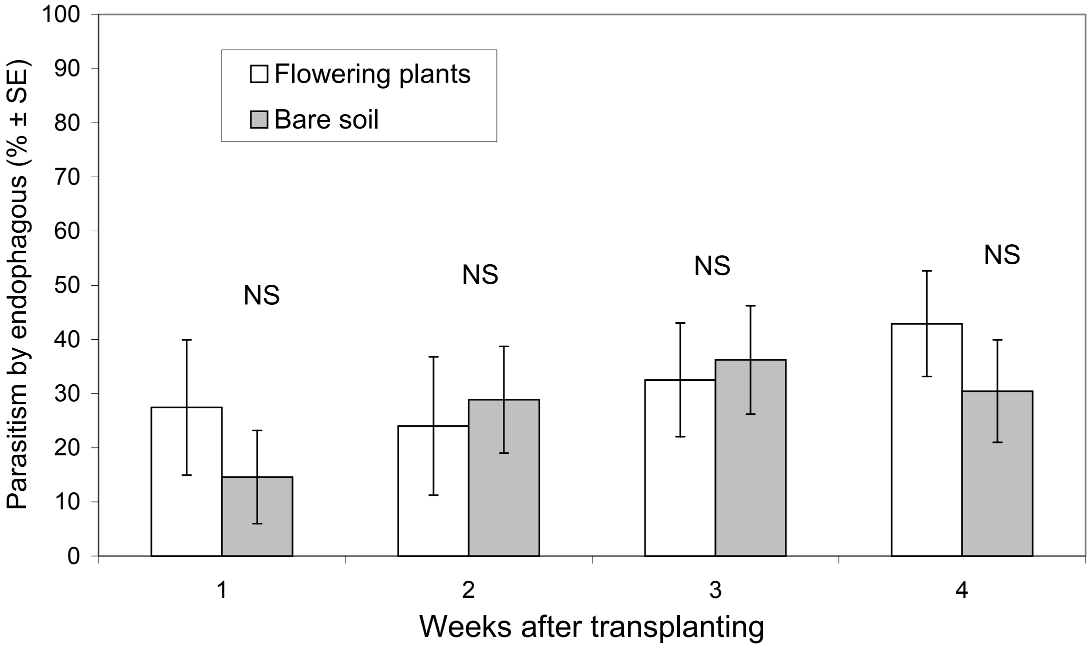

Figure 7. Percentage parasitism by endoparasitoids in 2002 as function of the weeks after transplanting. Bars indicate standard error of the mean (SE). NS: P>0.05 (chi-square test).

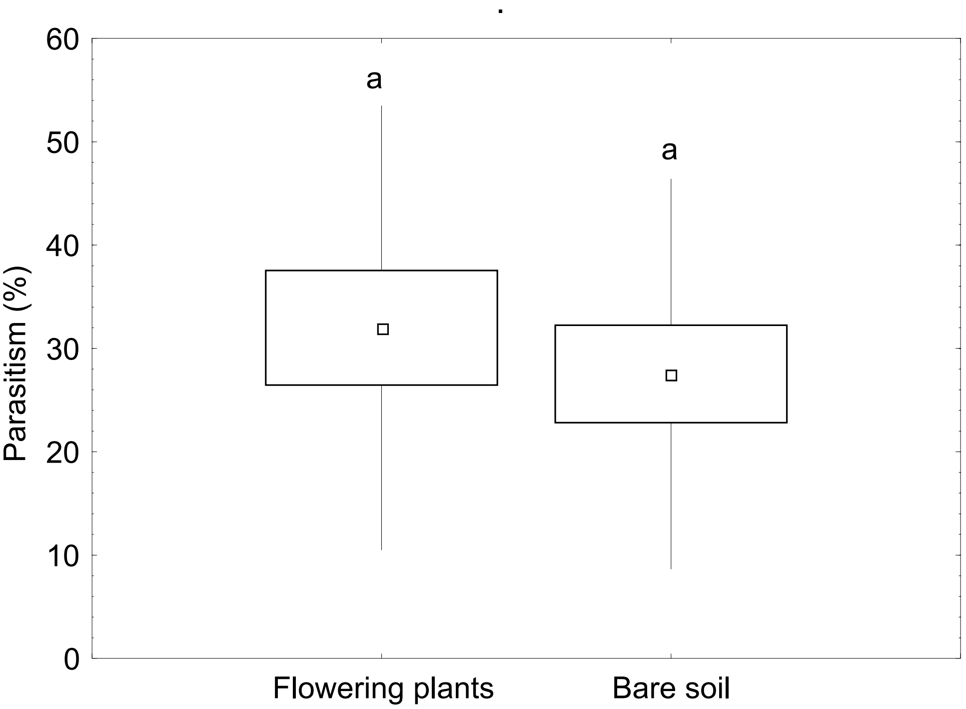

Figure 8. Comparison of the % parasitism by endoparasitoids in "flowering plants" and "bare soil" plots in 2002. Data pooled for all weeks. Same letters indicate P>0.05 from ANOVA (see Table 2).

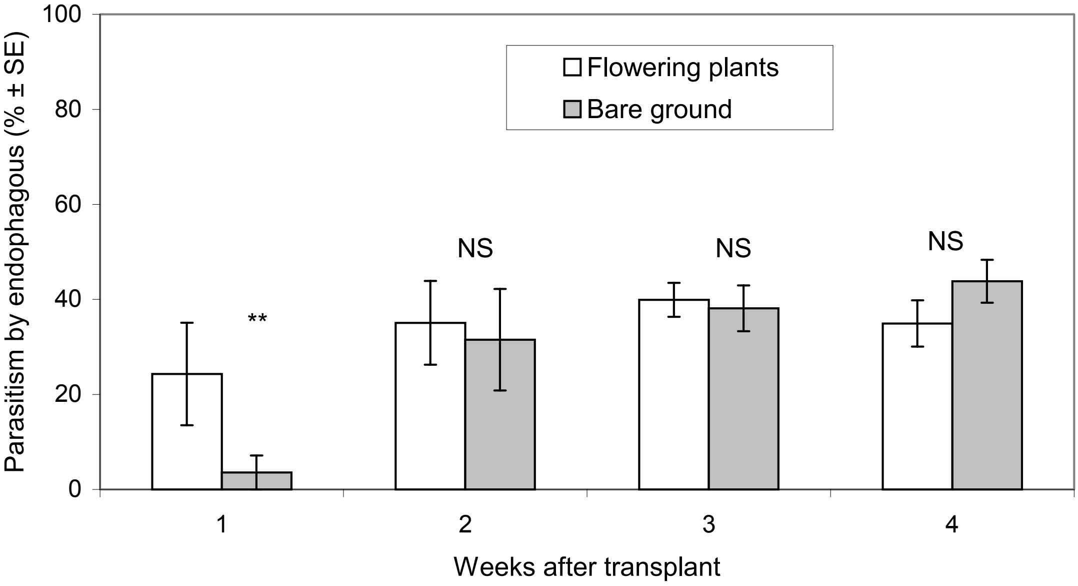

Figure 9. Percentage parasitism by endoparasitoids in 2003 as function of the weeks after transplanting. Bars indicate standard error of the mean (SE). NS: P>0.05 (chi-square test).

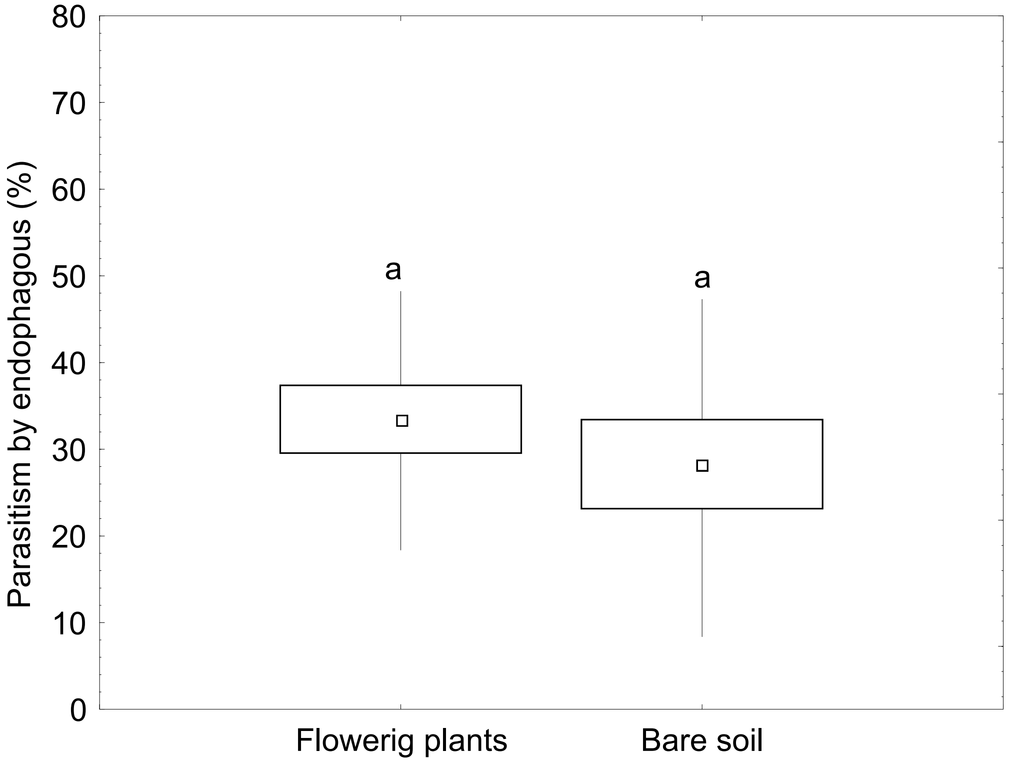

Figure 10. Comparison of the % parasitism by endoparasitoids, in “flowering plants” and “bare soil” plots in 2003. Data pooled for all weeks. Same letters indicate P>0.05 from ANOVA (see Table 2).

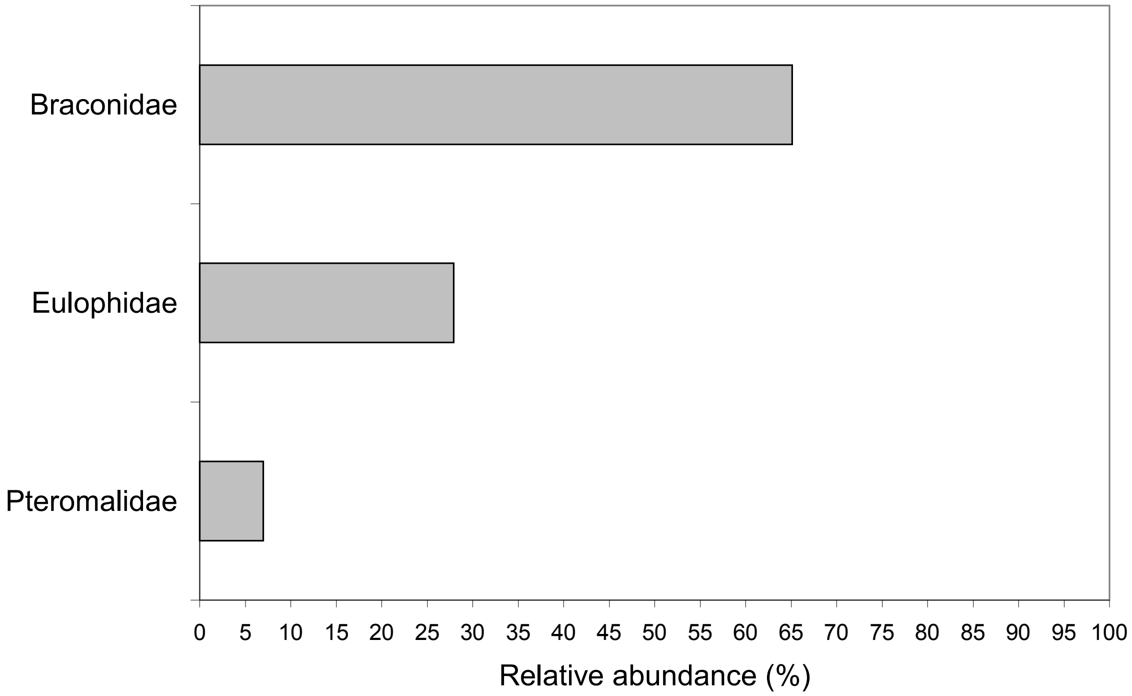

Figure 11. Relative abundances (%) of the families of the parasitoids emerged from the hosts collected in field.

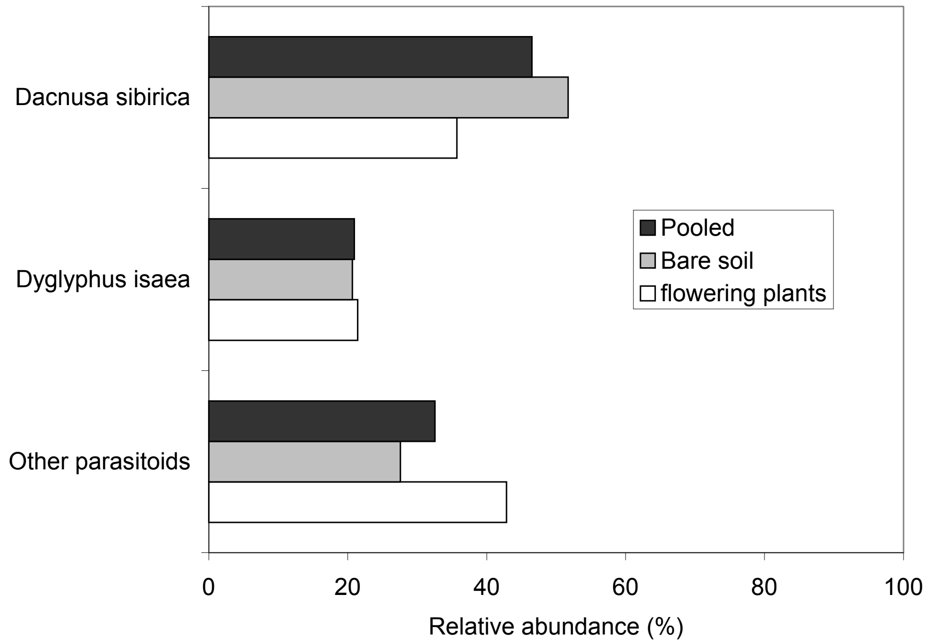

Figure 12. Relative abundances (%) of the parasitoid species emerged from the hosts collected in field.

The reason of this differential effect of flowering plants between ecto- and endoparasitoids is very intriguing, but still unknown.

A comparison of the total parasitism in the two treatments as function of the weeks after transplanting is shown in Figure 13 for 2002 and Figure 14 for 2003. In 2003, the interaction "treatments" *x* "weeks after transplanting" showed a P value very close to the significance level (P=0.060). This tendency to a "time dependent effect" of the flowering strips is evident in Figures 13 and 14, which show that the increase in parasitism in lettuce plots surrounded by flowering field strips is higher in the first week after transplanting. This observation is corroborated by the statistical analysis by means of chi-square test shown in Figures 13 and 14, which reveal a significant difference in the total parasitism between the two treatments. This time-dependent trend in parasitism is evident also in 2003 for both ecto- and endo-parasitoids (Figures 4 and 9), while in 2002 flowering plants significantly enhanced parasitism by ectoparasitoids in the 2nd and 3rd week after transplanting (Figure 3). Thus, the data illustrate that flowering plants induced an earlier start of parasitism in the lettuce plots, in comparison with the plots surrounded by bare soil. This effect was evident for total parasitism as well as for parasitism by either ecto- or endo-parasitoids.

In Figure 11 the relative abundances of parasitoid families which emerged from lettuce leaves are shown. Braconidae (65%) was the most abundant family, followed by Eulophidae (28%). Pteromalidae accounted only for 7% of the total of parasitoids emerged. The endoparasitoid *Dacnusa sibirica* Telenga (Braconidae) was the most abundant parasitoid in lettuce, representing the 46.5% of the total counts (pooled data of "flowering plants" and "bare soil" plots), followed by the ectoparasitoid *D. isaea* (20.9%; Eulophidae) (Figure 12). The relative abundance of *D. sibirica* and *D. isaea* in the two treatments was similar for the two types of plots.

The parasitoid composition on lettuce showed some differences in comparison with the agromyzid parasitoids collected form weedy margins (see chapter 4). In weedy margins, the

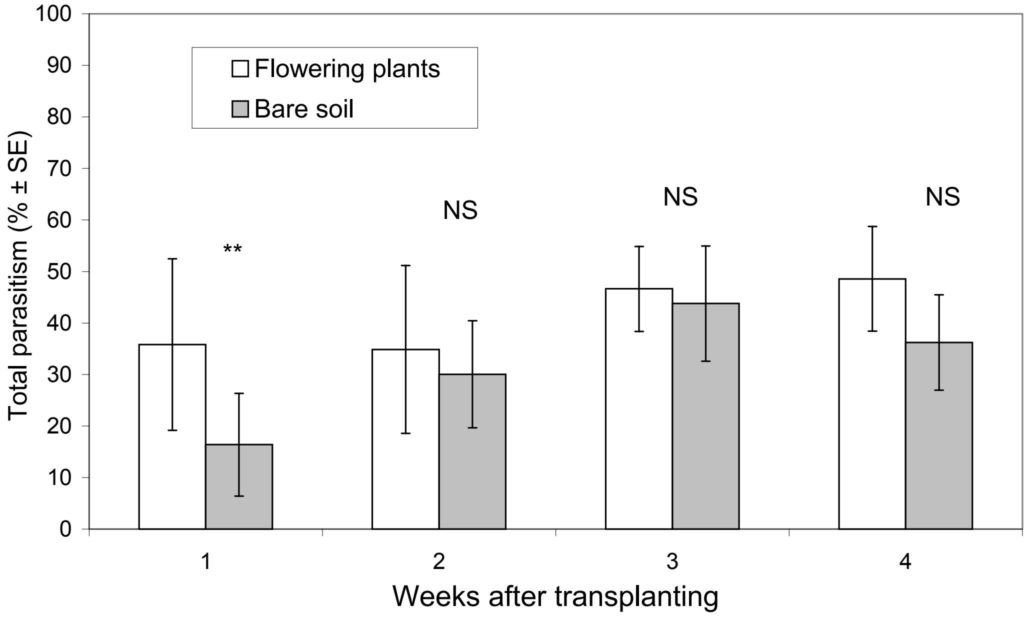

Figure 13. Percentage total parasitism in 2002 as function of the weeks after transplanting. Bars indicate standard error of the mean (SE). **: P< 0.01; NS: P>0.05 (chi-square test).

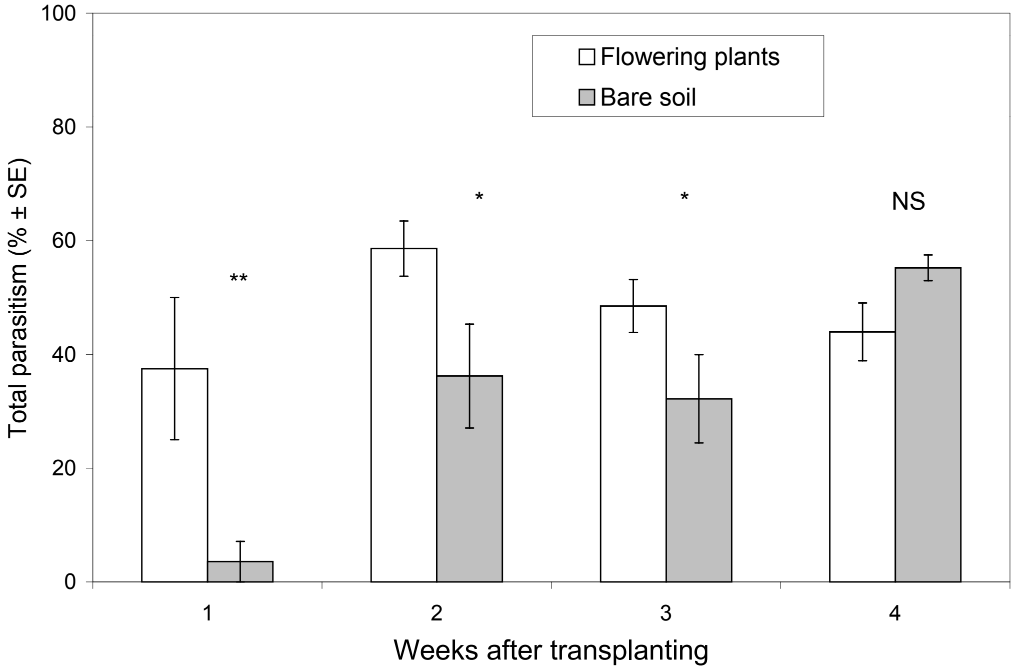

Figure 14. Percentage total parasitism in 2003 as function of the weeks after transplanting. Bars indicate standard error of the mean (SE). **: P< 0.01; *: P< 0.05; NS: P>0.05 (chi-square test).

dominant group were eulophids followed by braconids. In that study, the dominant parasitoid was the eulophid *Pedioubius metallicus* (Nees), representing 18.2% of the total, followed by *D. isaea* (Walker) (12.7%). The *Dacnusa* group, including four different species, was well represented with a relative abundance of about 14%.

The number of injured leaves and the type of damage (punctures or mines) close to the day of harvesting is presented in Table 3. Our data show that the percentage of mined leaves and the percentage of punctured leaves are not significantly different for the two treatments, though these parameters were somewhat lower in the lettuce surrounded with "flowering plants". In general, low damage was recorded in both treatments and this might be ascribed to the very limited use of pesticides on the organic farm where the experiments were carried out. The absence of chemical sprays in all the experimental plots may have enhanced conservation biological control, so also in the lettuce plots surrounded by bare soil. A number of studies confirms that the suppression of chemical sprays against leafminers can significantly enhance the natural parasitism against these pests (see references in the introduction). An example forms a field study carried out in northern Italy, which demonstrated that leafminer parasitism in untreated lettuce plots was significantly higher than in sprayed lettuce plots (Lanzoni et al., 2003). In a study of leafminer pests in tomato in the USA, Oatman and Kennedy (1976) found that repeated applications of broad spectrum insecticides (i.e. methomyl) on fresh market tomatoes resulted in increased numbers of the pest *Liriomyza sativae* Blanchard and, at the same time, a decreased percentage of parasitized leafminers. Johnson et al. (1980) found that parasitism of *L. sativae* by the larval-pupal parasitoid *Chrysocaris parski* Crawford was reduced ca. 40% in plots treated with an insecticide (methomyl), in comparison with an untreated plot.

In general, to answer the question as to whether flowering plant strips improve parasitoid efficacy is very complex, and influenced by many factors (see e.g. Wäckers et al., 2005). The hypothesis that floral nectar can decrease pest pressure by providing sugar to parasitoids and other natural enemies that would otherwise be sugar-limited has its origins in anecdotal and semi-quantitative observations of increased parasitism rates and biological control in the vicinity of flowering plants (Heimpel and Jervis, 2005). More recently, thorough reviews showed positive and negative effects due to the establishment of flowering field margins within landscape management (Wackers, 2005; Winkler, 2005). The way by which researchers, agronomists and farmers have attempted to provide plant foods to natural enemies can be divided into a "shotgun" and a "directed" approach (Gurr et al., 2005). The shotgun approach is based on the assumption that the net effect of habitat manipulation on pest management is beneficial. Directed approaches use empirical information, ecological theory or modelling to guide practices. In other words, the shotgun approach is only based on

Table 3. Injury of lettuce leaves as function of the different treatments. Within each column, same letters indicate P>0.05 (ANOVA).

Treatment	Healty leaves/lettuce head (% ± SD)	Punctured leaves/lettuce head (% ± SD)	Mined leaves/lettuce head (% ± SD)
Lettuce surrounded with flowering plants	88,1 ± 9,7a	15,8 ± 8,3a	0,9 ± 2,1a
Lettuce surrounded with bare soil	75,1 ± 10,8a	23,0 ± 10,9a	0,9 ± 1,7a

broad extrapolation from other studies and the belief that "diversity helps", rather than with the direct approach which postulates that "appropriate diversity helps" (Gurr et al., 2005). Laboratory experiments and sophisticated field tests seem crucial in the selection process of the suitable seed mixture (e.g. Winkler, 2005).

In our field experiments, no negative effects were observed of the flowering field strip on the crop. Our results clearly demonstrated that the flowering strips did not negatively affect pest densities of agromyzids. Moreover, the plots surrounded by flowering plants did not show any damage caused by other pests species.

Our data seem to demonstrate that flowering plants increased parasitism of agromyzids, and that parasitism occurred earlier than normally in crops without flowering field strips. So flowering field strips may lead to a better synchronization between agromyzid hosts and their parasitoids. However, the augmentation of parasitoids and parasitism did not result in a significant reduction of the agromyzid pest when compared with fields surrounded with bare soil, although pest damage was somewhat lower in lettuce with flowering field strips, and parasitism in the bare soil field was also very high, which might have masked the effect of the flowering field edge. In addition, the fact that we did not find significant differences may be ascribed to the generally very low density of agromyzids in both treatments of lettuce, and we propose, therefore, to repeat these experiments at higher pest densities.

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Section 3

The role of insect bioindicators in landscape management evaluation: a comparative study using different functional insect groups

Chapter 7

Diptera Syrphidae as rural landscape bioindicators: analysis of several northern Italian agroecosystems

Chapter 8

Analysis of biodiversity by means of a multiple-sampling system approach: a comparative study of insect and plant diversity and their relationships at landscape scale

Chapter 7

Diptera Syrphidae as rural landscape bioindicators: analysis of several northern Italian agroecosystems

Abstract
The syrphid fauna was sampled in nine rural sites characterized by different vegetation and landscape structures within agroecosystems of northern Italy. The aim of the work was to study the syrphid fauna in these landscapes and to evaluate the quality of the environment by means of the faunistic data collected. Sampling was by Malaise traps and yellow sticky traps that were baited with different kinds of glue. Malaise traps proved to be the most productive monitoring system and 55 syrphid species were sampled, while yellow-glue and yellow-spray traps sampled only 26 and 25 syrphid species, respectively. Despite the greater productivity, the Malaise trap failed to collect some species. The highest number of syrphid species was recorded in sites that were earlier characterized to be of "high" complexity. In spite of this general trend, the landscape-complexity criterion was not reliable for characterization of syrphid diversity, because "low" complexity habitats had higher numbers of syrphid species than "intermediate" ones. Among vegetation types, "hedgerow and abundant grass and flower strips" had most syrphid species. Sites were analysed also by multivariate analysis and the ordination was partially coherent with sites characterized by vegetation types. A standard method for Syrphidae that calculates a "biodiversity maintenance function", Syrph the Net, was used to evaluate sites. The use of Syrph the Net in northern Italian agroecosystems proved to be an effective and practical tool to evaluate the quality of rural environments.

Introduction

Due to the growing interest to understand and use functional biodiversity in rural landscapes, suitable biological indicators have to be identified for evaluation of the quality of ecological interventions in rural landscapes. The use of hoverflies (Syrphidae; Diptera) (= syrphids) as bioindicators has been suggested by many authors (e.g. Speight, 1986; Duelli and Obrits, 1998; Sommaggio, 1999; Speight and Castella, 2001). Several factors favour the use of syrphids as bioindicators, the primary one being the presence of species that show different environmental requirements. The possibility to easily identify most species, at least in Central Europe, and the presence of detailed biological studies are additional practical features. The use of Malaise traps as a standardised collecting method has been proposed as another important feature (Speight et al., 1998). Unfortunately, this trapping method is costly, which often results in a low sampling frequency. In addition, Sommaggio and Burgio (2003) have suggested that Malaise trapping can be selective and may underestimate the presence of some species.

In agriculture landscapes Syrphidae have been studied mainly for their importance in pest control. In a few studies, hoverflies have been used as bioindicators, and these focussed

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on infrastructure conservation within the rural landscape (e.g. Sommaggio and Burgio, 2004). Speight et al. (2002) used hoverflies to evaluate the quality of rural management in order to increase biodiversity. Speight et al. (2002) applied Syrph the Net, a sophisticated expert system for syrphid communities developed during the 1990's (Speight et al., 1998; Speight and Castella, 2001). The principal output of Syrph the Net is a "biodiversity maintenance function" (=BDMF), which is the ratio between observed and predicted species. The former is obtained by sampling. The latter is provided by the Syrph-the-Net database by taking the available regional list of species and matching the habitat preferences of each species to the habitats available at the site (Speight and Castella, 2001). An additional parameter is the ratio between the observed-but-not-predicted species and the observed species.

The main object of the research described in this chapter was to study syrphid populations in nine rural sites characterized by different vegetation and landscape structure. Various approaches were used to analyse the effect of vegetation and landscape on syrphid biodiversity, including classical biodiversity analysis, multivariate statistical analysis and Syrph the Net. A specific aim was to try to evaluate the quality of the rural environment by using the list of Syrphidae collected. In addition, different trapping techniques were compared in order to develop a sampling protocol that could be employed in environmental evaluation.

Material and methods

Description of sampling areas

The study was carried out in 2004 by sampling hoverfly populations in nine arable sites within the rural landscape of Modena and Reggio Emilia in northern Italy (Figure 1). In this region, the local government has applied the European Community agroenvironmental measures within Law 2078/92 at a local scale by funding the planting of hedgerows to implement an ecological network in the landscape (Burgio et al., 2000; Morisi, 2001; Regione Emilia-Romagna, 2001).

The area investigated was approximately 166 hectares in size. Three different types of vegetation were sampled:

1. Hedgerows with abundant grass and wild-flower strips;
2. Hedgerows with small grass strips;
3. Grass and wild flower strips (weedy margins) without hedgerows.

In this study hedgerows are considered to be linear corridors with a dominance of trees and shrubs. They are either accompanied by an adjacent abundant grass and wild flower strip (first habitat type) or not (second habitat type). Grass and wild flower strips are margins without shrubs and trees (third habitat type).

The sites that were sampled were placed in three different landscape categories (Table 1 and Figure 1):

1. High complexity landscape (HLC): well connected corridors and presence of many hedgerows;
2. Intermediate complexity landscape (ILC): less connected corridors than in category 1, and presence of only some hedgerows;
3. Low complexity landscape (LCL): isolated corridors and presence of few and isolated hedgerows.

The landscape categories were classified by measuring the structural complexity of the ecological corridors around the sites. A Geographical Information System (GIS) was used for mapping landscape characteristics. The linear development of the hedgerow network (LDHN) in a circle with a radius of 500m was calculated for each site. This parameter was used to

Table 1. Characteristics of sites investigated.

Vegetation typology	Landscape complexity	Site code	Exposure
Hedgerow with small grass strip	High	Maa4	North – South
Hedgerow with small grass strip	Low	Maa11	East – West
Hedgerow with small grass strip	Intermediate	Ma4	North – South
Hedgerow with grass and wild flower strip	High	Maa5	North – South
Hedgerow with grass and wild flower strip	Low	Maa14	North – South
Hedgerow with grass and wild flower strip	Intermediate	Ma3	East – West
Grass and wild flower strip	High	Me4	North – South
Grass and wild flower strip	Low	Me5	East – West
Grass and wild flower strip	Intermediate	Me2	North – South

determine the complexity of each landscape category. The following landscape categories were used: high landscape complexity if LDHN>1500m; intermediate landscape complexity if 1000<LDHN<1500m; low landscape complexity if LDHN<1000m. Using this criterion, and by calculating the average LDHN in the three sites within each category, the mean linear development was 1944m in the "high complexity landscape", 1346 in the "intermediate complexity landscape" and 900m in the "low complexity landscape".

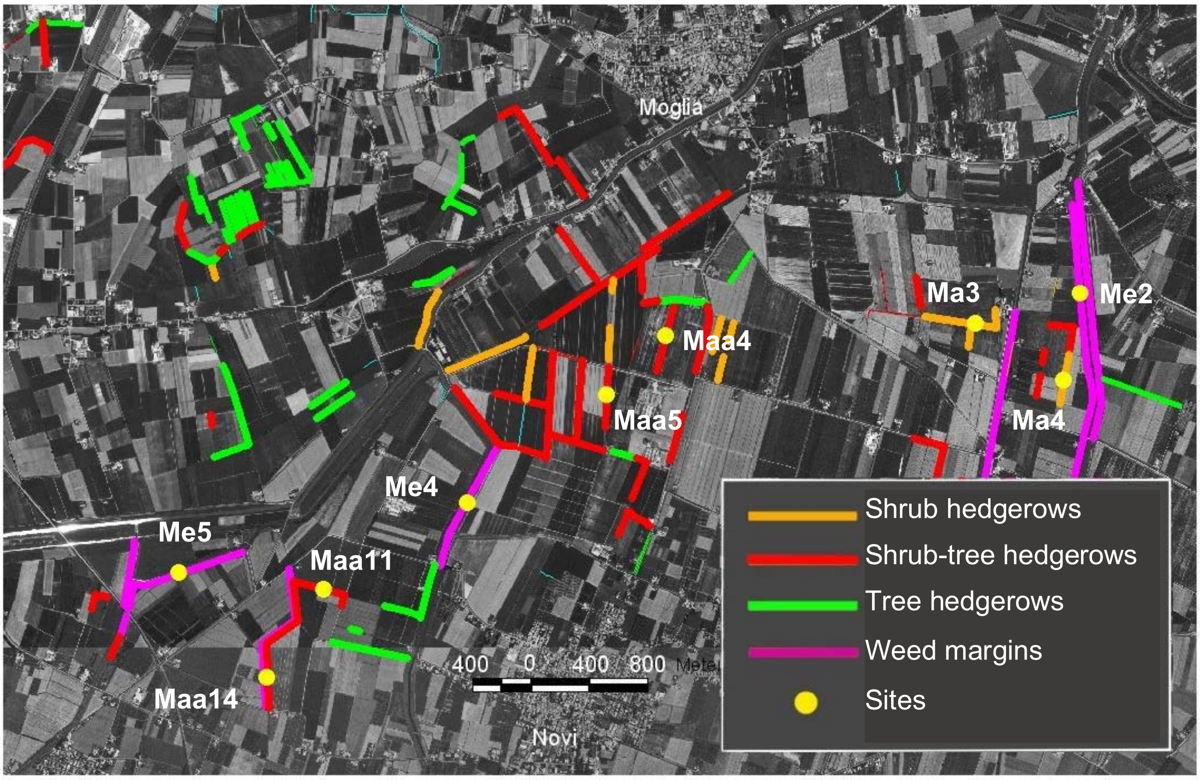

Figure 1. GIS map of the investigated landscape, showing the sites sampled and the main ecological features, including linear corridors, hedgerows with trees, hedgerows with shrubs, and weed margins. Spots indicate the sampling sites.

Monitoring techniques

Hoverflies were monitored between April and September 2004 by means of three sampling techniques: Malaise traps were baited with 70° alcohol, yellow traps (plastic plates with a diameter of 20 cm) baited with traditional glue (Zapicol®, Zapi S.p.A) and yellow traps baited with a yellow spray glue (Visspray®, Siapa S.p.A.).

For each site the following traps were set: one Malaise trap and four yellow traps, two of which were baited with traditional glue and two with spray glue. Samplings were carried out every three weeks by collecting the adults caught in the Malaise trap and by substituting new yellow traps.

Species nomenclature was according to Speight (2004).

Data analysis

Hoverfly species diversity was compared among sites by Principal Component Analysis (PCA). Two different inputs for PCA were used:

- abundance: a matrix of relative abundances from Malaise traps only;
- presence/absence: a matrix with data from both Malaise and yellow traps.

Correspondence Analysis (CA) (Pielou, 1984; Manly, 1994) was carried out to ordinate the sites on the basis of the percentage of species belonging to the different larval trophic category, on the matrix $\boldsymbol{p}$ x $\boldsymbol{n}$, where $\boldsymbol{p}$ = larval category and $\boldsymbol{n}$ = sites. The larval trophic category was decided according to the information in Rotheray (1993).

Syrph the Net was applied to the matrices in order to evaluate the quality of each site. Syrph the Net is a standard method initially developed for Atlantic Europe and then extended to Central Europe. The first applications of Syrph the Net in Italy showed some drawbacks (Sommaggio et al., 2005). First of all, detailed regional lists of Syrphidae species were available for only a few areas such as the eastern Padania Plain (northern Italy). Next, for some species the biological information provided by Speight for North and Central Europe differed from what we found for our area. For example *Eumerus sogdianus* Stackelberg is described in the Syrph-the-Net database as present in “open ground, dry, unimproved pasture and montane grassland, farmland on sandy soils, especially coastal dune systems, and sandy alluvial floodplains, plus humid, unimproved grassland”. But in the Padania Plain this species is almost ubiquitously occurring and sometimes in dense populations (Burgio and Sommaggio, 2002; Sommaggio, unpublished data). In the present paper Syrph the Net was used by applying the method of Speight and Castella (2001) but integrating data on the local syrphid fauna from regional lists (Daccordi and Sommaggio, 2002; Burgio and Sommaggio, 2002) and personal information of the authors of this chapter on the biology of particular species. Syrph the Net was used on the total number of species collected per site by all traps. In the analysis of data, migratory species were excluded.

To compare the frequency of catches among trap types (Malaise traps, yellow traps baited with glue and yellow traps baited with spray glue) a two-way analysis of variance was applied with the *a posteriori* Bonferroni test (P = 0.05), using trap types (Malaise - yellow glue trap - yellow spray trap) as main effect and sites as randomized blocks. Since we were interested only in comparing the relative efficacy of the different types of traps, the nine sites were used as dependent samples (blocks) without considering any effect of the different landscape contexts and vegetation types, because these two sources of variation were arranged in a factorial design without replication.

Results and discussion

Comparative analysis of the different collecting techniques

In Tables 2-4 the lists of species sampled with each sampling method are shown, including the total and relative abundances. Malaise traps proved to be the most productive monitoring system with 55 species sampled. Yellow glue and yellow spray traps sampled only 26 and 25 species, respectively. Despite the greater productivity, the Malaise trap failed to collect some species. Additionally, in a few cases the number of species collected by yellow traps was high, such as at site Me2 where 9 species were collected on the yellow trap which were not found in the Malaise trap (Table 5). The most abundant species sampled by means of Malaise traps was *Melanostoma mellinum* (L.) (31.1% of the total of captures), followed by *Episyrphus balteatus* (de Geer) (21.1%), *Sphaerophoria scripta* (L.) (23.4%) and *E. sogdianus* (5.3%); all the other species showed relative abundances under 3%. For yellow glue traps, the most abundant species were *E. balteatus* (32.1%), *Eristalis tenax* (L.) (31%), *Eristalinus aeneus* (Scopoli) (10.4%), *S. scripta* (6.2%) and *Eristalis arbustorum* (L.) (6.2%). For yellow spray traps, the most abundant species were *E. balteatus* (32.8%), *S. scripta* (15.7%), *E. tenax* (16.6%), *E. aeneus* (12.9%) and *E. arbustorum* (11.7%). The Malaise and Yellow traps showed in general a different spectrum of species sampled, and a detailed analysis of the frequency of catches is shown in Figure 2 for the most abundant species sampled in the study. Malaise traps collected a higher number of species. They were more effective in sampling predator species (Figure 2) and species considered rare for rural landscapes (i.e. saproxylic species), that were not sampled by yellow traps. On the other hand, Malaise traps were not efficient in sampling some very common species like *E. tenax*, *E. arbustorum*, *E. aeneus.* Analysis of variance and the Bonferroni test were employed in order to detect differences among collecting techniques. *E. aeneus* and *E. balteatus* were collected more frequently in yellow traps in comparison with Malaise traps, but there were no statistical differences between the two types of glue used for yellow traps, for these three syrphid species. *E. tenax* and *E. arbustorum* were more common in yellow traps, but *E. tenax* was more frequent in yellow glue traps, while *E. arbustorum* was more frequent in yellow spray traps. Finally, *E. sogdianus, S. scripta, M. mellinum* and *E. sepulchralis* populations were statistically more frequent in Malaise traps than yellow traps.

Differences between sites

A summary of the number of species sampled in the different landscapes categories and vegetation types is shown in Table 6. Among the three categories of “landscape complexity”, the highest number of Syrphidae species was registered in sites belonging to “high complexity”. Among plant types, “hedgerow and abundant grass and flower strips” showed the higher number of species.

In Table 7 the total number of Syrphidae species belonging to different larval categories sampled at each site is shown. The number of species with predator larvae sampled per site ranged between 9 and 20, corresponding to 44,5 % and 65,4 % of the total number of species, respectively.

The data matrix of Table 7 was analysed by Correspondence Analysis (Figure 3). The percentage of species belonging to the “saprophagous” category was highly associated with sites Ma4, Me5, MAa4 and Maa5, while the percentage of species belonging to the “predator” category was associated with sites Me4, Ma3 and Maa11. Finally, the percentage of species belonging to the “phytophagous” category was strongly associated with site Maa14. One site (Me2) was grouped in an intermediate position. Sites highly associated with saprophagous

Table 2. List of species sampled by Malaise trap per site; numbers indicate the total specimens sampled and % the relative abundance.

Species	Sites									%
	Maa5	Maa11	Maa14	Maa4	Ma4	Ma3	Me2	Me4	Me5	
Anasimyia contracta Claussen & Thorp	0	0	0	0	0	0	0	0	1	0,03
Anasimyia transfuga (L.)	0	0	0	0	0	0	0	1	0	0,03
Brachyopa scutellaris Robineau-Desvoidy	0	0	0	0	0	0	0	0	1	0,03
Ceriana conopsoides (L.)	0	0	0	1	0	1	0	0	0	0,06
Chalcosyrphus nemorum (F.)	0	0	1	0	0	0	0	0	0	0,03
Cheilosia intonsa Loew	0	0	2	0	0	0	0	0	0	0,06
Cheilosia ranunculi Doczkal	0	0	1	0	0	0	0	1	5	0,21
Chrysotoxum cautum (Harris)	0	0	0	0	1	6	0	1	0	0,24
Epistrophe eligans (Harris)	5	0	0	1	0	1	2	1	0	0,30
Epistrophe nitidicollis (Meigen)	1	0	0	0	0	0	0	0	0	0,03
Episyrphus balteatus (de Geer)	123	75	60	128	76	193	17	32	6	21,07
Eristalis arbustorum (L.)	1	1	0	3	0	2	0	0	0	0,21
Eristalis similis (Fallen)	3	0	0	0	0	0	0	0	0	0,09
Eristalis tenax (L.)	0	3	1	0	0	11	0	1	0	0,47
Eristalinus aeneus (Scopoli)	4	0	5	11	2	1	0	9	1	0,98
Eristalinus sepulchralis (L.)	0	1	1	0	0	0	0	0	0	0,06
Eumerus amoenus Loew	3	9	7	7	3	10	1	12	0	1,54
Eumerus argyropus Loew	0	0	1	1	0	0	0	0	0	0,06
Eumerus sogdianus Stackelberg	7	24	6	56	16	21	2	42	4	5,28
Eumerus strigatus (Fallen)	0	0	0	0	0	2	0	0	0	0,06
Eupeodes corollae (F.)	10	7	5	18	4	20	1	6	2	2,17
Eupeodes latifasciatus (Macquart)	0	1	2	3	0	1	0	0	0	0,21
Eupeodes luniger (Meigen)	1	0	0	2	0	0	0	1	3	0,21
Helophilus pendulus (L.)	1	0	1	1	1	1	1	1	0	0,21
Helophilus trivittatus (F.)	0	0	0	0	1	1	0	0	0	0,06
Heringia brevidens (Egger)	2	4	0	0	0	0	0	0	0	0,18
Heringia verrucula (Collin)	1	0	0	0	0	0	0	0	0	0,03
Lejogaster tarsata (Megerle in Meigen)	0	0	0	2	0	0	0	0	0	0,06
Melanostoma mellinum (L.)	258	91	122	206	7	68	23	216	57	31,10
Melanostoma scalare (F.)	4	1	1	1	0	1	0	3	2	0,39
Meliscaeva auricollis (Meigen)	1	0	1	0	0	0	0	0	0	0,06
Merodon avidus (Rossi)	0	0	1	0	0	0	0	0	0	0,03
Neoascia interrupta (Meigen)	3	0	0	0	0	1	0	1	0	0,15
Neoascia podagrica (F.)	0	0	1	0	0	0	0	1	0	0,06
Neoascia tenur (Harris)	1	0	0	0	0	0	1	0	1	0,09
Paragus bicolor (F.)	0	0	0	0	1	11	0	3	0	0,45
Paragus bradescui Stanescu	0	0	0	0	0	0	0	1	0	0,03
Paragus haemorrhous Meigen	8	1	4	5	0	12	3	2	1	1,07
Paragus hyalopteri Marcos-Garcia & Rojo	0	0	0	0	2	9	0	0	0	0,33
Paragus pecchiolii Rondani	0	0	25	11	0	24	0	3	0	1,87
Paragus quadrifasciatus Meigen	0	3	0	5	0	6	0	10	0	0,71
Parhelophilus versicolor (F.)	6	0	0	13	0	0	0	0	0	0,56
Pipizella maculipennis (Meigen)	1	0	0	1	0	3	2	1	1	0,27
Pipizella viduata (L.)	1	0	6	2	0	3	0	5	2	0,56
Platycheirus fulviventris (Macquart)	0	0	0	6	0	0	0	1	0	0,21
Scaeva pyrastri (L.)	0	1	0	0	0	2	0	0	0	0,09
Sphaerophoria rueppellii Wiedemann	1	9	5	28	0	5	0	53	0	3,00
Sphaerophoria scripta (L.)	69	11	84	129	32	173	59	131	99	23,35
Syritta flaviventris Macquart	1	0	0	1	0	0	0	0	0	0,06
Syritta pipiens (L.)	5	0	4	0	1	3	0	10	0	0,68
Syrphus ribesii (L.)	0	0	0	2	0	0	0	0	0	0,06
Syrphus torvus Osten-Sacken	0	1	0	0	0	0	0	0	0	0,03
Syrphus vitripennis Meigen	1	0	0	1	0	3	1	2	0	0,24
Triglyphus primus Loew	0	1	1	0	0	0	0	0	0	0,06
Xanthogramma pedissequum (Harris)	1	4	0	0	1	13	0	0	0	0,56
Total of species	28	19	25	27	14	30	12	28	15	
Total of specimens	523	248	348	645	148	608	113	551	186	

Table 3. List of species sampled by yellow spray trap per site; numbers indicate the total specimens sampled and % the relative abundance.

Species	Sites									%
	Maa5	Maa11	Maa14	Maa4	Ma4	Ma3	Me2	Me4	Me5	
Cheilosia ranunculi Doczkal	0	0	0	0	0	0	0	2	2	0,29
Chrysotoxum cautum (Harris)	1	1	0	0	0	5	4	1	0	0,86
Episyrphus balteatus (de Geer)	42	15	130	134	13	91	18	10	3	32,76
Eristalinus aeneus (Scopoli)	25	8	39	20	28	7	3	41	8	12,86
Eristalinus sepulchralis (L.)	11	2	8	0	0	2	3	15	17	4,17
Eristalis arbustorum (L.)	19	9	13	34	12	10	34	23	9	11,71
Eristalis similis (Fallen)	1	3	1	0	0	1	0	0	0	0,43
Eristalis pertinax (Scopoli)	0	0	0	0	0	0	0	1	0	0,07
Eristalis tenax (L.)	26	6	24	21	21	69	29	27	9	16,67
Eumerus amoenus Loew	0	0	0	0	0	1	0	0	0	0,07
Eupeodes corollae (F.)	0	1	1	3	2	1	0	1	2	0,79
Eupeodes luniger (Meigen)	0	1	0	0	0	0	1	0	0	0,14
Eumerus sogdianus Stackelberg	0	3	0	0	0	1	0	0	0	0,29
Helophilus trivittatus (F.)	1	0	0	1	0	0	0	0	0	0,14
Helophilus pendulus (L.)	0	1	0	1	0	0	0	0	0	0,14
Melanostoma mellinum (L.)	0	2	1	0	0	0	0	0	1	0,29
Merodon avidus (Rossi)	0	0	1	0	0	0	0	0	0	0,07
Mesembrius peregrinus (Loew)	0	0	0	1	0	0	1	0	0	0,14
Myathropa florea (L.)	0	2	1	0	0	2	0	0	0	0,36
Parhelophilus versicolor (F.)	0	0	0	0	0	0	1	0	0	0,07
Pipizella maculipennis (Meigen)	0	0	0	0	0	2	0	0	0	0,14
Sphaerophoria scripta (L.)	14	5	14	23	60	28	52	5	18	15,73
Syrphus ribesii (L.)	0	0	1	1	0	0	2	0	0	0,29
Syrphus vitripennis Meigen	0	3	0	4	0	2	2	2	0	0,93
Syritta pipiens (L.)	2	1	0	0	1	3	1	0	0	0,57
Total of species	10	16	12	11	7	15	13	11	9	
Total of specimens	142	63	234	243	137	225	151	128	69	

Table 4. List of species sampled by yellow glue traps per site; numbers indicate the total specimens sampled and % the relative abundance.

Species	Sites									%
	Maa5	Maa11	Maa14	Maa4	Ma4	Ma3	Me2	Me4	Me5	
Chrysotoxum cautum (Harris)	0	0	1	2	0	3	2	0	0	0,72
Episyrphus balteatus (de Geer)	12	26	52	123	23	81	14	22	5	32,08
Epistrophe eligans (Harris)	0	1	0	0	0	0	0	0	0	0,09
Eristalinus aeneus (Scopoli)	1	12	5	30	29	4	0	37	2	10,75
Eristalinus sepulchralis (L.)	2	0	0	3	0	0	0	4	0	0,81
Eristalis arbustorum (L.)	1	5	12	10	2	9	2	24	4	6,18
Eristalis tenax (L.)	30	40	13	38	75	72	12	51	15	31,00
Eumerus amoenus Loew	0	0	0	0	0	2	0	0	0	0,18
Eumerus sogdianus Stackelberg	0	0	0	0	2	0	0	0	0	0,18
Eupeodes corollae (F.)	1	3	1	2	4	1	8	2	0	1,97
Eupeodes latilunulatus (Collin)	0	0	0	0	0	0	0	2	0	0,18
Eupeodes luniger (Meigen)	0	1	0	0	0	1	0	0	0	0,18
Helophilus trivittatus (F.)	0	0	0	0	0	1	0	1	0	0,18
Melanostoma mellinum (L.)	2	0	0	0	44	0	1	0	1	4,30
Myathropa florea (L.)	3	1	0	16	0	10	2	2	0	3,05
Paragus haemorrhous Meigen	0	0	0	0	0	0	1	0	0	0,09
Paragus quadrifasciatus Meigen	0	0	0	0	1	0	0	0	0	0,09
Parhelophilus versicolor (F.)	0	0	0	1	1	0	0	0	0	0,18
Scaeva pyrastri (L.)	1	0	0	0	0	0	0	0	0	0,09
Sphaerophoria scripta (L.)	1	3	0	9	40	3	3	0	10	6,18
Syritta flaviventris Macquart	0	0	0	0	1	0	0	0	0	0,09
Syritta pipiens (L.)	0	1	0	1	1	0	2	0	2	0,63
Syrphus ribesii (L.)	0	0	1	0	0	1	0	1	0	0,27
Syrphus vitripennis Meigen	1	1	1	0	0	0	0	1	0	0,36
Volucella zonaria (Poda)	0	0	1	0	0	0	0	0	0	0,09
Xanthogramma pedissequum (Harris)	0	0	0	0	0	1	0	0	0	0,09
Total of species	11	11	9	11	12	13	10	11	7	
Total of specimens	55	94	87	235	223	189	47	147	39	

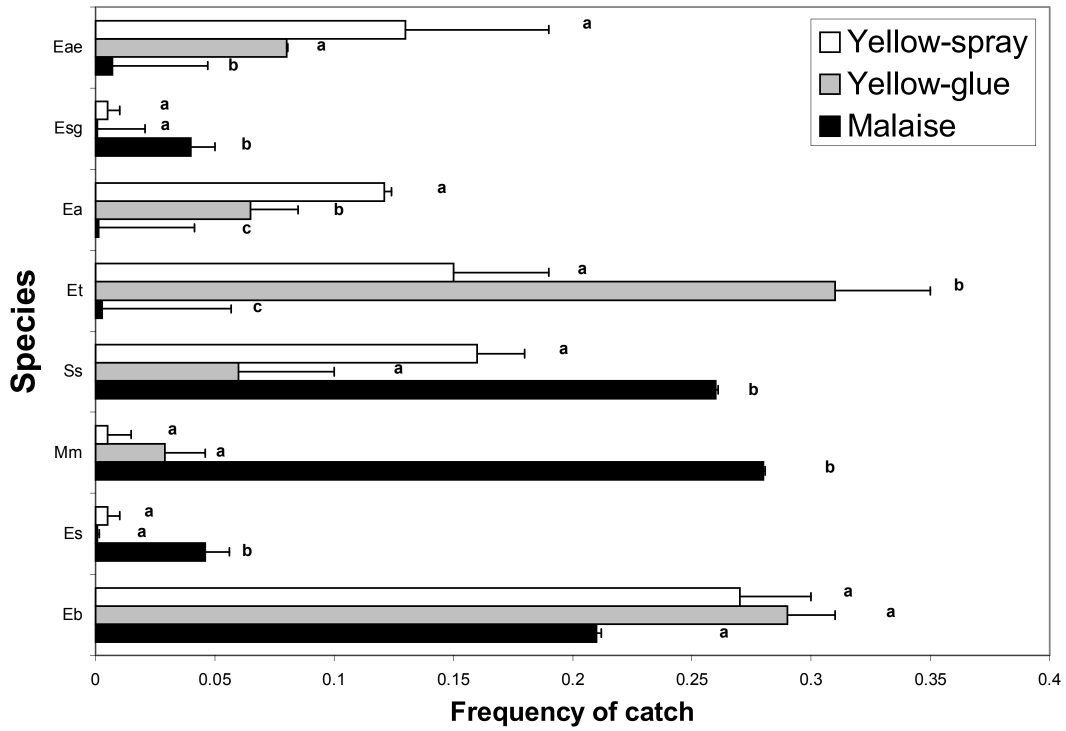

Figure 2. Frequency of the most abundant syrphid species for each trap system. Bars indicate standard errors of means. Different letters within each species indicate significant differences by the Bonferroni test (P<0.05). Species: Eae = *Eristalinus aeneus*; Esg = *Eumerus sogdianus*; Ea = *Eristalis arbustorum*; Et = *Eristalis tenax*; Ss = *Spharophoria scripta*; Mm = *Melanostoma mellinum*; Es = *Eristalinus sepulchralis*; Eb = *Episyrphus balteatus*.

Table 5. Number of syrphid species collected only by yellow traps, and not found in the Malaise traps. No = the numbers, and % = the percentage of species collected by yellow trap on the total species collected, at each site.

	Maa5	Maa11	Maa14	Maa4	Ma4	Ma3	Me2	Mw4	Me5
No	5	7	5	6	5	3	9	5	3
%	16,1	25,9	17,2	18,2	26,3	9,4	42,8	15,6	15,8

Table 6. Total number of syrphid species sampled by Malaise traps in each landscape and plant typology.

	No Syrphidae species
Landscape complexity	
High	43
Intermediate	31
Low	36
Plant typology	
Hedgerows with grass and wild flower strip	47
Hedgerows with scarce grass strip	39
Grass and wild flower strip	31

Table 7. Total number of syrphid species belonging to different larval categories sampled at each site.

	Sites								
	Maa5	Maa11	Maa14	Maa4	Ma4	Ma3	Me2	Me4	Me5
Predator larvae	18	17	13	17	9	20	11	18	9
Saprophagous larvae (acquatic)	9	6	8	10	6	7	7	10	6
Saprophagous larvae (terrestrial)	2	1	2	3	2	2	1	1	2
Phytophagous larvae	2	2	6	3	2	3	2	3	2

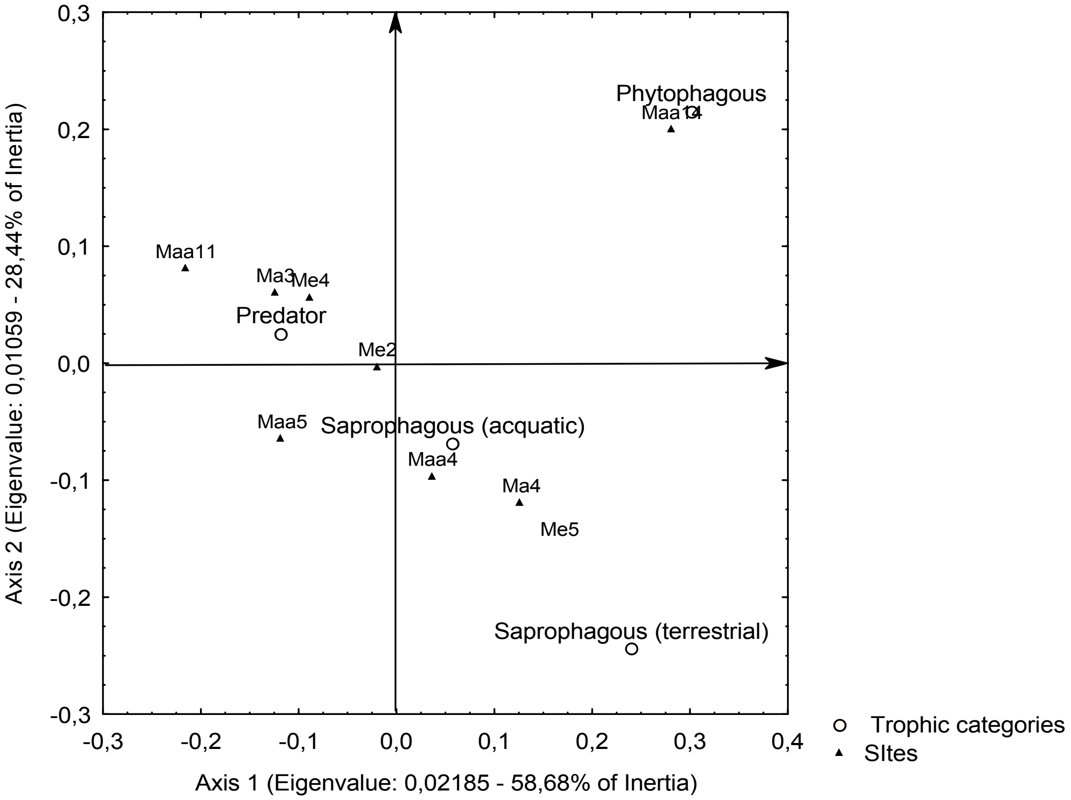

Figure 3. Ordination of percentage of the species belonging to the four larval categories in each site. On the axes and between parentheses are the percentages of inertia explained by the axes.

species were characterised by a big canal (Me5) or irrigation ditches (Ma4 and Maa4). The number of phytophagous species sampled in the Maa14 site, characterised by a hedgerow with grass and wild flower strips, was two or three times higher in comparison with the other sites and this was probably due to the high plant diversity at this site. *Merodon avidus* (Rossi) and *Cheilosia latifrons* (Zetterstedt) were sampled by Malaise trap only at site Maa14.

The syrphid data were also ordered by Principal Component Analysis (PCA) on the basis of the presence/absence matrix (Figure 4) and the relative abundance matrix (Figure 5). The ordination represented in Figure 4 was only partially coherent with plant typology and the sites were divided into two main sub-groups. For example, two sites characterised by "hedgerow with small grass strip" (Maa11, Ma4) were grouped in the same cluster. On the other hand, the sites characterised by "grass and wild flower strip without hedgerow" (Me2,

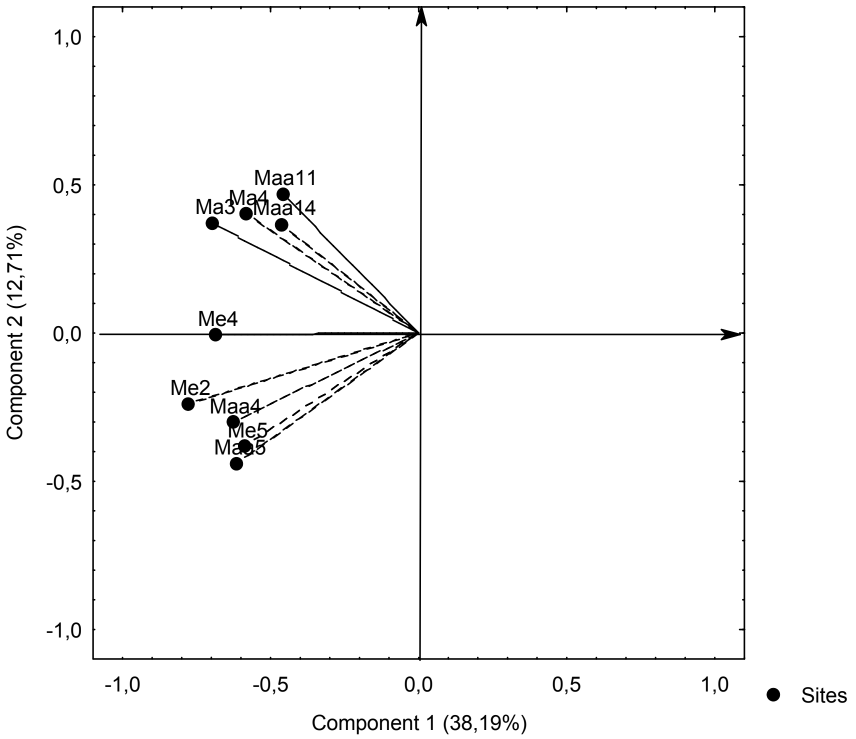

Figure 4. Ordination of the sites on the basis of the presence/absence matrix of Syrphidae. On the axes and in parentheses are the percentages of variance explained by the axes.

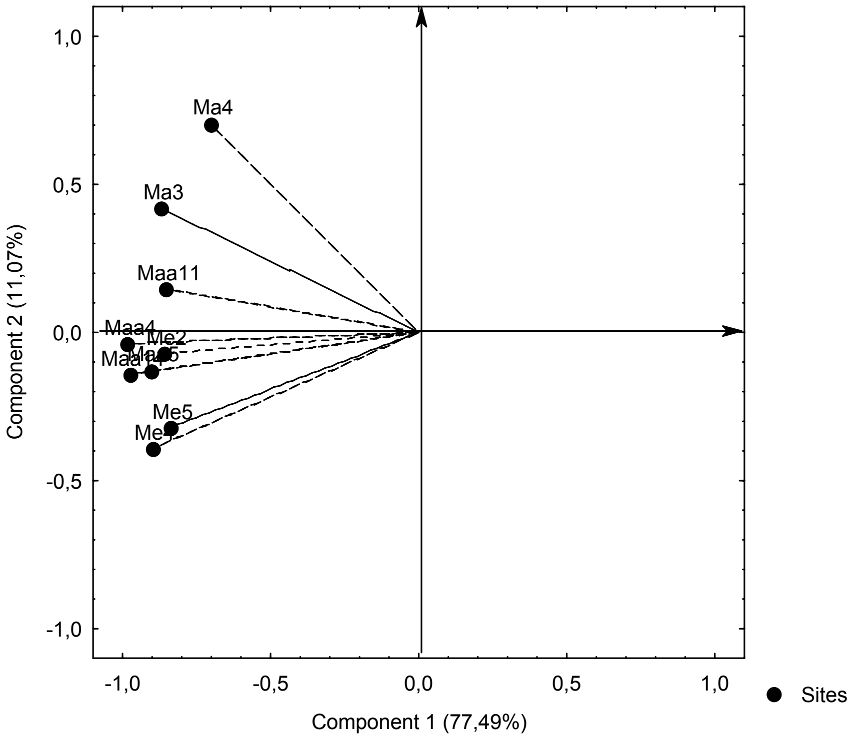

Figure 5. Ordination of the sites on the basis of the matrix of relative abundances of Syrphidae. On the axes and in parentheses are the percentages of variance explained by the components.

Me5 and Me4) were in the same sub-groups, even though Me4 is separated geographically from the other sites. Other inconsistencies can be observed by the ordination of data using PCA: for example, sites Maa5 and Maa4, characterized by hedgerows, clustered with sites without hedgerows. The analysis of data by PCA using the relative abundance matrix did not improve the ordination of data. In this case also sites were grouped according to the plant typology (Figure 5).

Among the species sampled, *Ceriana conopsoides* (L.) and *Brachyopa scutellaris* Robineau-Desvoidy are considered rare species, recorded in deciduous forests (*Fagus* and *Quercus*) with overmature trees and in deciduous forest with mature *Acer*, *Alnus* or *Fraxinus*, respectively (Speight, 2004). For this reason these species are considered strong landscape bioindicators. In view of the fact that no deciduous forests are present in our study area, the larvae of these species may have emerged from old trees within the mature hedgerows that are present at the sites.

Syrph the Net

The analysis by Syrph the Net is shown in Table 8. Speight and Castella (2001) gave a list of examples about the use of Syrph the Net for environmental evaluation. Predicted species lists are generated from regional species pools, coupled to codified habitat, microhabitat and biological data for the species. At the site level, habitat association data are used to tailor the predicted list to site conditions, and a comparison between predicted and observed species lists is used to explore elements of site quality and site management (Speight and Castella, 2001). By means of this approach it is possible to calculate a “biodiversity maintenance function” of a site, which is an index based on differences between the occurrence of observed and expected species. If the pool of species predicted to occur in a particular habitat is observed at a target site, then the biodiversity maintenance function is performing at maximum efficiency in that habitat on that site (Speight and Castella, 2001).

From the analysis of our data by Syrph the Net, it can be seen that for six sites the maintenance biodiversity function ranged between 50 and 74%, showing good quality of the habitats *sensu* Speight et al. (2002). One site (me4) showed a value >75%, corresponding to top quality environmental conditions. Only two sites showed a value <50%, considered the critical value for a good-quality environment.

Table 8. Summary of the analysis employed by Syrph the Net.

Sites	Expected species	Observed species	Expected species not observed	Observed species not expected	Mantaining biodiversity function	Species observed not expected/observed species
Maa4	42	24	18	9	57.1%	17.6%
Maa5	42	24	18	8	57.1%	16.0%
Maa14	45	25	20	5	55.6%	10.0%
Maa11	44	22	22	4	50.0%	8.3%
Ma4	42	15	27	4	35.7%	8.7%
Ma3	42	25	17	7	59.5%	14.3%
Me4	30	23	7	9	76.7%	23.1%
Me5	31	15	16	4	48.4%	11.4%
Me2	31	17	14	4	54.8%	11.4%

An additional important parameter of Syrph the Net is the ratio between species "observed but not expected" and the total number of species collected. This parameter, quantifying the proportion of unexpected species at a micro-site, could reflect the influence of the environment surrounding the micro-site. In the present study the ratio of "species observed but not expected vs. the species collected" was highly correlated with the biodiversity function (Figure 6).This parameter is incorporating an extra "environmental component" and contributes to the analysis of the data. It can be interpreted as the addition of species by the environment surrounding the site. For example, site Me4 showed the highest values for the biodiversity function and the highest value of the percentage of unexpected species. The first value indicates that the micro-site is well conserved and the second parameter explains the influence of the environment surrounding the site, which, in this case, is characterised by "high landscape complexity". Also sites Maa4 and Maa5, located in an "high landscape complexity" surrounding, showed high values of this parameter. The site Maa14 includes an old and mature hedgerow. In this site the syrphid fauna showed a high richness, corresponding to a high value of the biodiversity maintenance function. On the other hand, the ratio of unexpected species is low, which is in agreement with the low ecological complexity of this site. The biodiversity function calculated in Maa14 by Syrph the Net is higher than 50%. On the other hand, this site is located in a low complexity area and the number of unexpected species is low. This example indicates how, by using Syrph the Net, the vegetation effect and landscape effect can be separated. More observations need to be done in order to validate and confirm our preliminary conclusions.

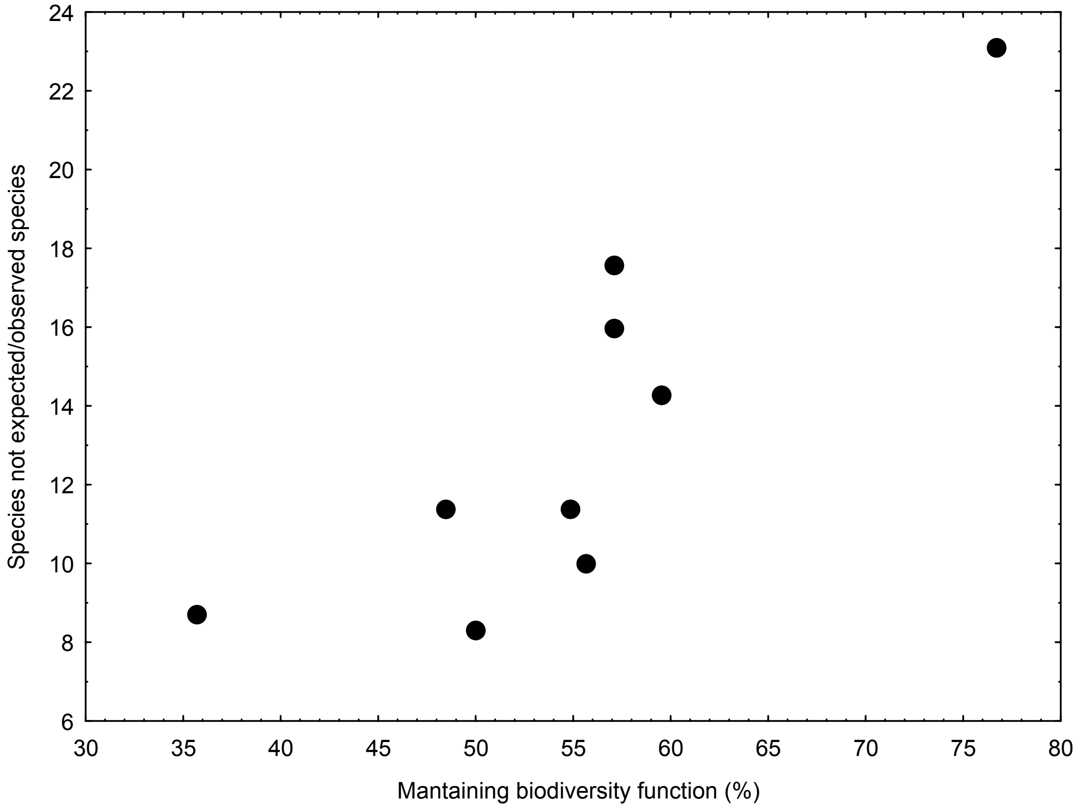

Figure 6. Correlation between the diversity function and the percentage of species observed but not expected (%) by Syrph the Net (R = 0.84; P<0.01, Spearman rank correlation).

The syrphid fauna sampled in the present study ranged from 12 to 30 species at the nine sites investigated, and a total of 55 species was recorded for all the areas monitored by means of Malaise traps. In other Italian rural landscape studies, the number of species collected ranged from 10 to 31 (Daccordi, 1979; Daccordi et al., 1988; Burgio et al., 1997; Burgio and Sommaggio 2002; Sommaggio and Burgio, 2004). A rigorous comparison of such data with those of the present research cannot be executed because of the use of different sampling techniques used and various crop and landscape types. A major problem is that few data are available for Malaise trap sampling in Italian rural landscapes. For example, in a study on an organic farm in northern Italy, 31 species were collected by Malaise traps. But other studies on organic farms with hand nets or colour trap sampling found far less species. The syrphid biodiversity sampled in the current study seems to be quite rich, and also includes uncommon and rare species for rural landscapes, like *C. conopsoides* and *B. scutellaris*. Malaise traps collected a total of 55 species, but yellow glue and yellow spray traps sampled only 26 and 25 species, respectively. In spite of this difference in efficacy, yellow traps sampled some species that were not sampled by Malaise traps. Moreover, yellow traps were more efficient in sampling some saprophagous and common species. The reasons for this phenomenon are unknown but it could be hypothesized that these saprophagous species are characterised by a flight behaviour that make them less suitable to be collected by Malaise traps.

Our results indicate that a multiple-trapping system could be a valid method for sampling syrphid species in a monitoring programme for environmental quality. The comparison of different methods of data analysis show that qualitative data (i.e. lists of species and multivariate analysis based on a presence/absence matrix) can be a valid tool to characterise rural habitats. Quantitative data collected by Malaise traps and yellow traps can be usefull to rank the relative abundances of species, but in many cases do not improve the environmental analysis. The use of Syrph the Net for northern Italian agroecosystems is a practical tool to evaluate the quality of rural environments (Sommaggio et al., 2005). The first results obtained in this study by Syrph the Net are promising. Now, this approach should be applied to other Italian rural landscapes for a fuller evaluation of its usefulness. It would be interesting to further test the opportunity to separate microhabitat and landscape effects on biodiversity by the two different functions of Syrph the Net. In Italy, hedgerow planting and natural vegetation management supported by local governments have been widely used during the last twenty years, especially in orchards. In Italy there are very few examples on management of biodiversity at the landscape scale. The Syrph the Net approach could be useful in evaluating the quality of rural management and the effects of management of biodiversity.

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Chapter 8

Analysis of biodiversity by means of a multiple-sampling system approach: a comparative study of insect and plant diversity and their relationships at landscape scale

Abstract

The general aim of this study was to investigate insect biodiversity patterns at a landscape scale in the intensively cropped area of the Emilia-Romagna region in northern Italy. A comparative analysis of insect bioindicators was carried out to compare the usefulness of different insect groups as bioindicators in order to evaluate the quality of rural landscapes and the effect of agro-environmental interventions. The species richness per site ranged between 20 and 35 for carabids, from 20 to 36 for butterflies, from 4 to 28 for sawflies, from 14 to 30 for syrphids and from 40 to 84 for plants. Carabids and syrphids provided reliable information about diversity at landscape scale, while butterflies and sawflies were better diversity indicators at micro-habitat scale. The richness of butterflies was strongly affected by occurrence of certain micro-habitats at the sites and not by the structural complexity around the sites. For example, the richness and abundance of butterfly species were significantly correlated with the number of plant species. Moreover, butterfly abundance was positively correlated with the percentage of weed cover. The species richness of some groups (i.e. syrphids and carabids) significantly increased from site scale, via the meso-scale (the species richness in each landscape category) to the landscape scale (total of species sampled for the whole landscape). Syrphids showed to be good rural landscape indicators, which confirms the conclusion expressed in the previous chapter. Carabids were affected by landscape complexity, but to a lesser extent than syrphids. Carabid richness and abundance were not clearly explained by the vegetation characteristics. Sawflies showed to be good micro-habitat indicators, but further studies are needed in different rural contexts before they can generally be used as reliable indicators. In this study, the importance to give a *functional meaning* to faunistic lists of insects in a ”landscape management approach” was stressed. For environmental analysis of the intrinsic quality of the cultivated areas or for the evaluation of the quality of ECAs, a multidisciplinary approach is needed for optimal discrimination of the different management solutions. The conservation status of the insect fauna can be also used as data bank for environmental evaluations at a local scale.

Introduction

Current ideas, supported by field studies, have pointed out the importance of spatial scale in ecological entomology. In particular, ecological studies seem to demonstrate that diversity patterns within a habitat may depend on processes at a larger spatial scale than the habitat (reviewed in Tscharntke and Brandl, 2004). Moreover, also in practical applications like landscape management a large-scale perspective was proposed for studying functional biodiversity. Recently the importance of scale in landscape ecology received, among others, attention with the creation of the study group “Landscape management for functional biodiversity” within IOBC (International Organization for Biological Control) (Rossing et al., 2003; 2006).

Agricultural intensification results in habitat destruction and fragmentation, and causes a strong negative impact on biodiversity. This structural simplification of ecosystems led to a disruption of functional biodiversity, with demonstrated negative effects on pest control (Altieri, 1999; Landis *et al.*, 2000). Biodiversity studies of rural landscapes classically concentrated on field or farm scale, while the landscape scale was scarcely investigated. But some studies focused on functional diversity on landscape scale (Landis and Haas, 1992; Marino and Landis, 1996; Holland and Fahrig, 2000; Menalled et al., 2003). However, many problems emerge with biodiversity studies at landscape scale, including (1) the choice of appropriate bioindicators, (2) the high costs of labour intensive studies, and (3) the lack of detailed regional taxonomic information for many arthropod groups. It is becoming increasingly apparent that explanations of diversity patterns vary with scale (Tscharntke and Brandl, 2004). It has also been demonstrated that the best predictors of biodiversity on a local scale may be very different from those on larger (i.e. regional or continental) scale (Willis and Whittaker, 2002). In addition, trophic interactions can also dramatically change over the geographic range of a species for a wealth of reasons, including genetic changes in plants and insect traits, in insect responses to plant resources, and in complex interactions between plant resistance and insect virulence (reviewed in Tscharntke and Brandl, 2004). As a result of this knowledge, we can conclude that data collected on small scale like an agricultural field cannot be extrapolated to a larger spatial context like a landscape. For these reasons, studies concerning the effect of complex factors like landscape fragmentation or the effects of landscape structure and management on functional diversity, need to be performed at the relevant spatial scale.

In Italy, a rural landscape perspective has been used to study the spatial-temporal patterns of some insect pests (Sciarretta et al., 2003; Ragaglini and Petacchi, 2004; Trematerra et al., 2004; Petacchi et al., 2005; Burgio et al., 2005; Ragaglini, 2006), or the host-parasitoid relationships (Lucchi et al., 2004), at meso or macro-scale, including the use of advanced approaches like geostatistics. An interesting example of the use of bioindicators to evaluate the environmental quality of meadows at a provincial scale is the survey of Orthoptera fauna within Belluno province (northern Italy) (Fontana et al., 2004). In this study, 186 localities found along 52 transects were monitored, but the study was not focused on the rural landscape. An example of biodiversity at a regional scale is the inventory of bird and plant communities carried out by the local government of the Emilia-Romagna region with the aim to evaluate the result of certain agro-environmental schemes on biodiversity (E-R report, 2006). This study contains many faunistic data at local scale, but it did not sufficiently consider ecological relationships between animal and plant diversity, and it does not contain information on other biota than faunistic data.

In conclusion, notwithstanding an increasing trend of studies on insect patterns at meso- or macro- scale, there is a lack of studies on functional biodiversity at the rural landscape scale level in Italy. Further, specific research should be done with the aim to explain the effect of landscape structure on arthropod diversity.

The general aim of this study was to investigate insect biodiversity patterns at a landscape scale in the intensively cropped area of the Emilia-Romagna region in northern Italy. First, a comparative analysis of insect bioindicators was carried out to compare the usefulness of different insect groups as bioindicators to evaluate the quality of rural landscapes and agro-environmental interventions. Next the conservations status of the insect fauna was studied to compile a list of the indicator fauna for quality assessment of the rural landscape, which can be used as data bank for environmental evaluations at a local scale.

Finally, we tried to obtain understanding of the relations among landscape structure and insect/plant diversity, in order to investigate the influence of landscape categories and vegetation types on animal and vegetational diversity patterns within the rural landscape.

Materials and Methods

Description of sampling areas

From 2002 to 2004, a 3-year study was done using a multiple-sampling system for insect and plant populations. The sampling sites were the same as mentioned in chapter 7. This chapter also has a map of the investigated area and the description of the landscape categories and vegetation types. Diptera Syrphidae (= syrphids or hoverflies), Lepidoptera (= butterflies), Coleoptera Carabidae (= carabids or carabid beetles) and Hymenoptera Symphyta (= sawflies) were selected as insect groups.

Monitoring techniques

Different sampling methods were used to monitor insect populations: i) pit-fall traps; ii) Malaise traps and iii) hand net sampling with visual-inspection. Plant communities were sampled by means of the phytosociological method of Braun-Blanquet (1932).

Insects

Pit-fall traps

Five pit-fall traps with vinegar as preserving liquid were placed at each site. Carabids were collected and counted every 3 weeks between April and November. Pit-fall traps were set close to the vegetation types typical for each site (see the description of the sampling areas in chapter 7). Carabids were identified at species level. Carabid diversity and population parameters were analysed by means of the number of species collected and the total numbers per trap and sampling date. Carabid nomenclature was according to Vigna Taglianti (2001).

Malaise traps

A Malaise trap was set up at each site. The traps were baited with 70% alcohol. Syrphids and sawflies were collected every 2-3 weeks between April and September. Syrphid species nomenclature was according to Speight (2004). Syrphid diversity and populations were analysed by means of the number of species and the total of specimens collected per trap.

Hand net

Butterflies were monitored with a hand net between April and September. Samplings were carried out every 3 weeks by collecting adults on a fixed transect of 200 meters following Pollard (1977) and Pollard and Yates (1993). Samplings were carried out at sunny conditions and between 11 A.M. and 15 P.M., while walking along a fixed trajectory and observing both sides of the transect. The time of sampling was 30 minutes for each transect. The collected adults were generally identified in the field and released after identification, except for some difficult to identify species, which were collected and identified in the laboratory. Butterfly nomenclature followed the Balletto and Cassulo (1995) check list. Data were expressed as the number of species sampled and as the number of individuals collected (frequency of catches).

Plant communities

Plant communities were sampled by means of the phytosociological method of Braun-Blanquet (1932). The vegetation composition based on all plant species present was recorded and the community structures were analysed for 28 sampling plots (*relevés* according to the nomenclature of Braun-Blanquet). Samplings were carried out in late spring when all the plant species can be recognized. Plant species were identified with the Italian Flora of Pignatti (1982). The abundance of each species in each sample was recorded and coded by means of the «cover-abundance» scale (Braun-Blanquet, 1932). All the records were tabulated for each site in order to be able to analyse the data and to discover relathionships between insect and plant at micro-habitat and landscape scale.

Data analysis

Biodiversity indices were analysed to compare the plant and insect biodiversity patterns among the sites, and among the landscape categories and vegetation types. In general, the species number was chosen as basic index of diversity for its simplicity. In some cases, other diversity indices were determined, like the Simpson and Shannon index, but this approach was applied with carefulness, because certain sampling methods (e.g. hand net) are not suitable for this kind of analysis.

Multivariate analyses (Principal Component Analysis and Correspondence Analysis) were carried out in order to ordinate the sites sampled on the basis of landscape and vegetation characteristics. With the multivariate analyses we tried to find potential associations among the variables. A multivariate approach was also chosen to correlate the occurrence of insect and plants richness/abundance with each site, or with landscape and vegetation characteristics.

A non parametric correlation analysis (Spearman test) was used to study the relationship between the number/abundance of insect species and vegetation parameters.

Results and Discussion

Influence of landscape complexity and vegetation types on insect and plant communities

In Table 1 the number of insect and plant species and the vegetation characteristics are listed for each site. The species richness appeared strongly dependent on the kind of biota: for example, the species richness per site ranged between 20 and 35 for carabids, from 20 to 36 for butterflies, from 4 to 28 for sawflies, from 14 to 30 for syrphids and from 40 to 84 for plants.

Plant richness was not strongly influenced by the complexity of the landscape around the sites. But it was clearly affected by the abundance of weed cover (Table 2) and by the variety of micro-habitats and vegetation types present at the same site, which is understandable. At the nine sampling sites, three main vegetation types were found (A= mesophilous grasslands, B= hygrophilous grasslands; C= shrub-woods and woods, see appendix for details) with some sub-types (B1, B2, B3, C1, C2, C3) that correspond to different micro-habitats. Plant diversity was clearly dependent on the number of vegetation types found at each site: the highest numbers of species were recorded in the most heterogeneous sites (Maa14: types C, B; Me4: types A,B; Me5: types A,B), while the homogeneous sites were less rich (Ma3, Maa4, Maa5, only type C). Plant diversity was also positively correlated with weed cover ($R=0,73$, $P<0.05$), whereas it has a tendency to be negatively correlated with high shrub cover ($R=-0,61$, $P=0.07$). The flora of the sites analysed

Table 1. Number of insect and plant species, and vegetation parameters for each site. ICSV = index of vegetation structural complexity. The site are described in chapter 7.

Sites	# syrphid species	# carabid species	# sawfly species	# butterfly species	# plant species	ICSV	% trees cover	% shrub cover	% weed cover
Maa5	28	27	13	24	41	5	83	58	28
Maa11	19	20	8	20	64	5	77	45	50
Maa14	25	29	28	36	84	4	60	50	50
Maa4	27	35	11	23	40	5	87	47	42
Ma4	14	28	5	27	44	4	61	56	45
Ma3	30	26	11	27	35	3	20	85	48
Me2	12	30	4	27	67	1	0	0	83
Me4	28	32	10	31	82	2	0	11	85
Me5	15	28	6	29	79	1	0	23	73
total	55	62	41	39	180				

Table 2. Correlation matrix (Spearman rank correlation) between the number of insect species and vegetation diversity.

	# sawfly species	# syrphid species	# carabid species	# butterfly species	# plant species	ICSV	% trees cover	% shrub cover	% weed cover
# sawfly species	1	**0.75 ***	-0,003	0,09	-0.09	0,52	0,45	0,56	-0.44
# syrphid species	**0.75***	1	-0,11	-0,008	-0,35	0,3	0,22	0,51	-0.29
# carabid species	-0.03	-0,11	1	0,34	0,3	-0.24	-0.15	-0.50	0,26
# butterfly species	0,09	-0,008	0,34	1	**0.71***	**-0.66***	**-0.70***	-0.18	0,56
# plant species	-0.09	-0,35	0,3	**0.71***	1	0.44	-0,55	-0.61	**0.73***
ICSV (°)	0,52	0,3	-0,24	**-0.66***	-0.44	1	**0.96***	0,52	**-0.76***
% trees cover	0,45	0,22	-0,15	**-0.70***	-0.55	**0.96*****	1	0,54	**-0.86****
% shrub cover	0,56	0,51	-0,5	-0.18	-0.61	0,52	0,54	1	-0.80**
% weed cover	-0.44	-0,29	0,26	0,56	**0.73***	**- 0.76***	**-0.86****	**-0.80****	1

was quite rich and, as expected, was composed mostly of weeds and grassland species. The following remarkable aspects were observed: a) the total amount of plant species (180) is the triple of the mean species richness of the single sites (60); b) the majority of species are rare; 72 were found at only one site); and c) many woody species and hydrophylous plants were present, some of which are quite rare in the rural landscape of the Po valley.

The number of plant species was significantly correlated with the richness of butterfly species ($R=0.71$, $P<0.05$) and abundance ($R=0.76$, $P<0.05$) (Tables 1, 2 and 3; Figures 1 and 2). Moreover, butterfly abundance was positively correlated with the percentage of weed cover ($R=0.75$, $P<0.05$) (Figure 3). Sawflies and syrphid species richness showed R values of 0.56 and 0.51, respectively, when related to the percentage of shrub cover, but the correlations were not significant ($P = 0.10$) (Tables 1, 2 and 3). Also, butterfly richness was inversely correlated with the Index of vegetation structural complexity ($R= -0.66$, $P<0.05$) and the percentage of tree cover ($R= -0.84$, $P<0.01$) (Figure 4), parameters representing the structural architecture of the site (Tables 1, 2 and 3). Finally, among insect groups, the number of sawflies and syrphid species were positively correlated ($R=0.75$, $P<0.05$) (Figure 5).

Table 3. Correlation matrix (Spearman rank correlation) between the insect abundances and vegetation diversity.

	sawfly abundance	syrphid abundance	carabid abundance	butterfly abundance	# plant species	ICSV	% trees cover	% shrub cover	% weed cover
sawfly abundance	1	0,53	0,01	0,1	0,11	0,5	0,42	0,45	-0.38
syrphid abundance	0,53	1	0,45	-0,2	-0,41	0,41	0,38	0,4	-0.35
carabid abundance	0,01	0,45	1	0,2	-0,16	-0,29	-0,18	0,16	≈0
butterfly abundance	0,1	-0,2	0,2	1	**0.76***	-0,29	**-0.84****	-0.36	**0.75***
plant species	0,11	-0,41	-0,16	**0.76***	1	0.44	7	-0.61	**0.73***
ICSV (°)	0,5	0,41	-0,29	**-0.76***	-0.44	1	**0.96***	0,52	**-0.76***
% trees cover	0,42	0,38	-0,18	**-0.84****	-0.55	**0.96*****	1	0,54	**-0.86****
% shrub cover	0,45	0,4	0,16	-0.36	-0.61	0,52	0,54	1	-0.80**
% weed cover	-0,38	-0,35	≈0	**0.75***	**0.73***	**- 0.76***	**-0.86****	**-0.80****	1

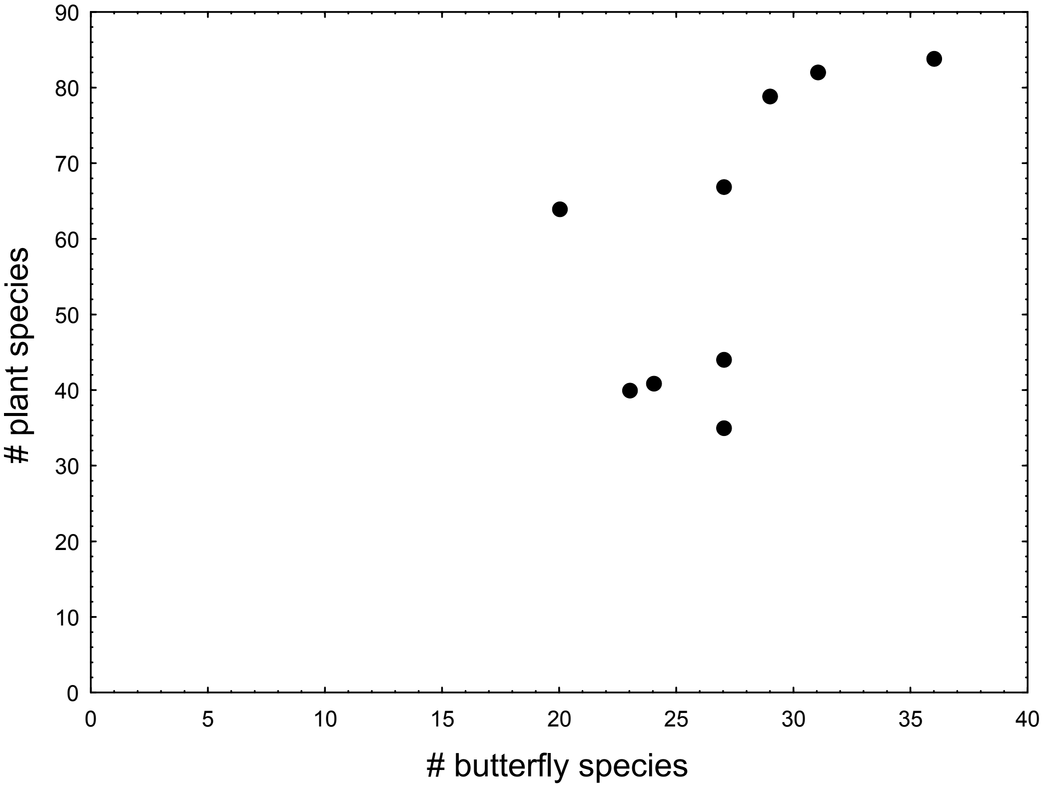

Figure 1. Correlation between butterfly richness and number of plant species (R =0.71, P <0.05).

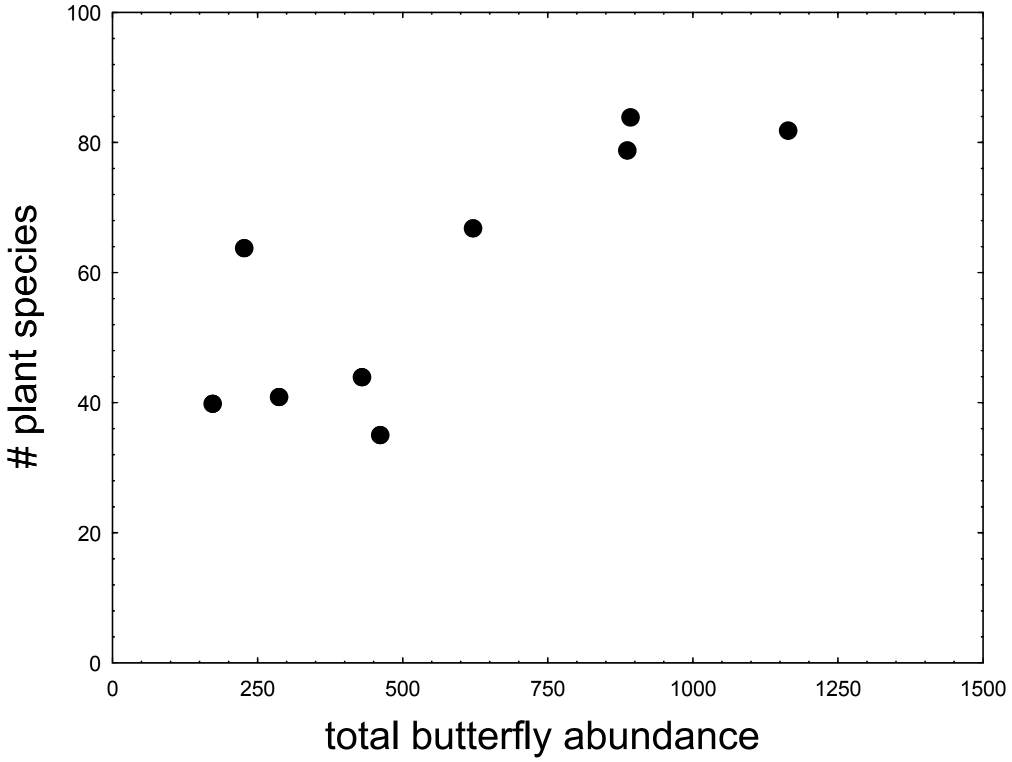

Figure 2. Correlation between butterfly abundance and number of plant species (R = 0.76, P< 0.05).

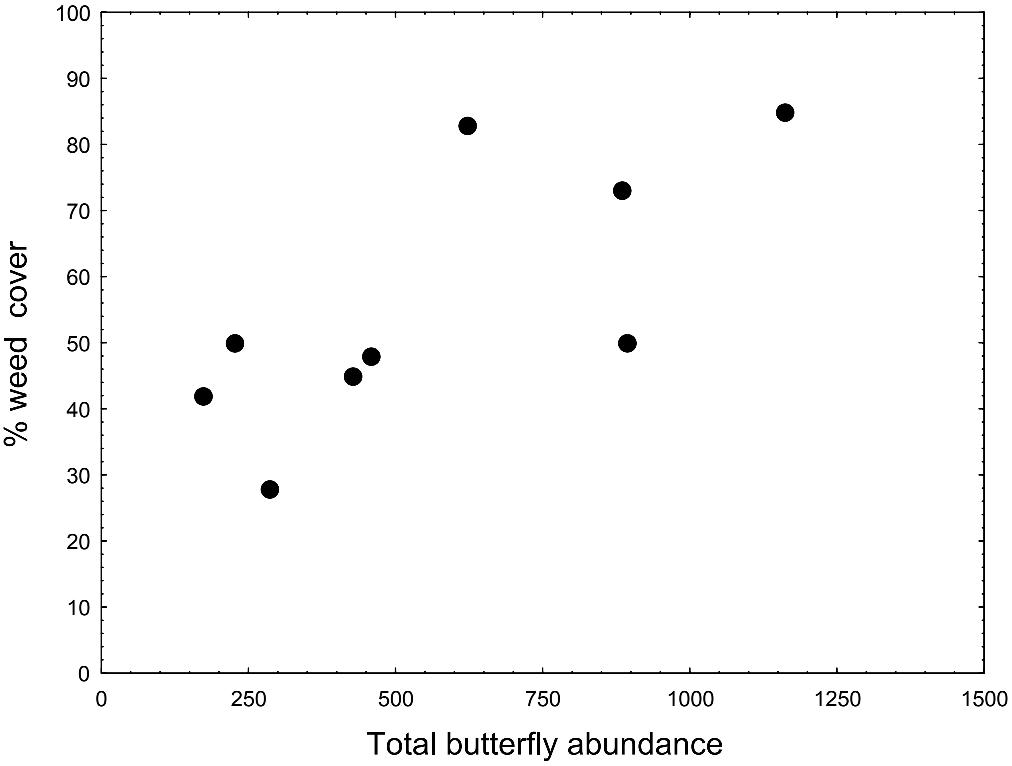

Figure 3. Correlation between butterfly abundance and percentage of weed cover (R = 0.75, P< 0.05).

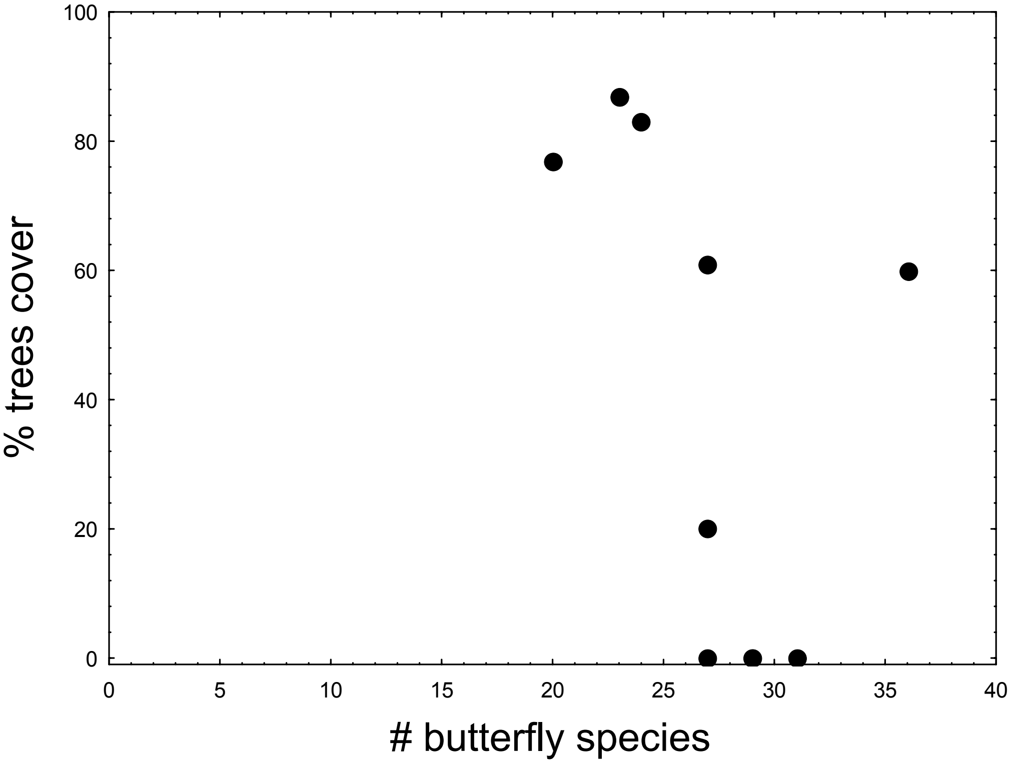

Figure 4. Correlation between number of butterfly species and percentage of tree cover (R= -0.70, P<0.05).

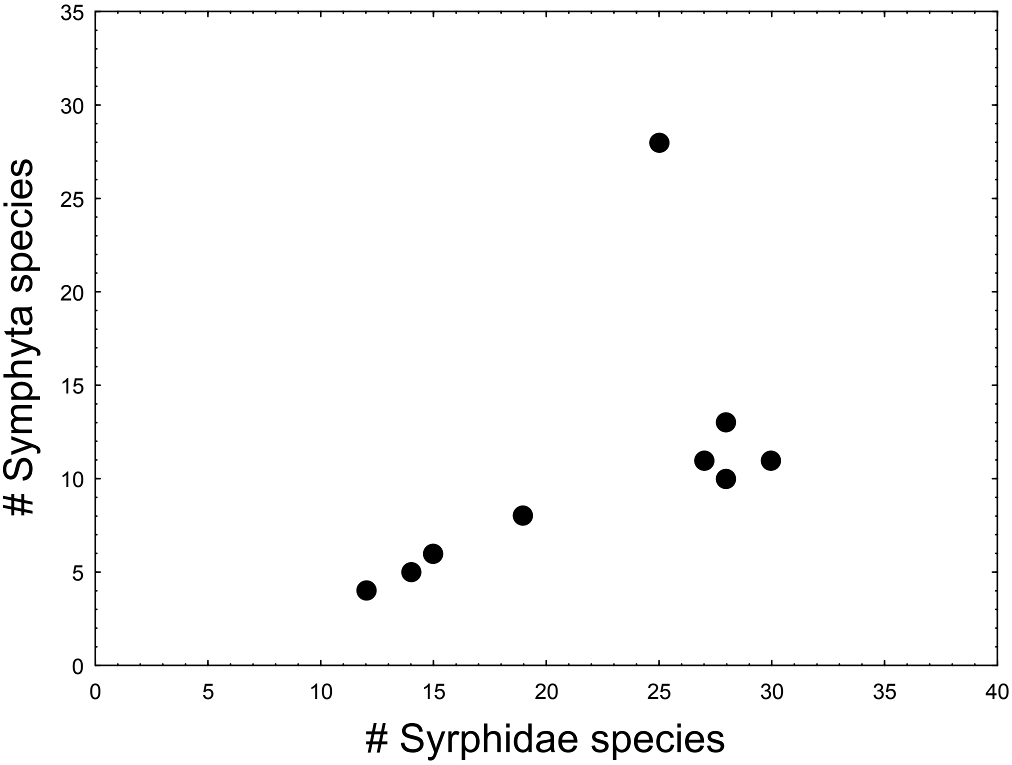

Figure 5. Correlation between number of syrphid species and the number of Symphyta species (R=0.75, P<0.05).

In Table 1 the site diversity (total number of species at a certain sampling site; this corresponds to the microhabitat or point diversity *sensu* Whittaker, 1977), and the whole landscape diversity (total number of species at a certain landscape category) are listed. When analysing species richness at different scales, a consistent effect of spatial scale on the biodiversity pattern of some groups can be shown. For some groups (i.e. syrphids and carabids) the species richness significantly increased from field level (site diversity), via meso-scale (insect diversity within each landscape category), to whole landscape level (total of species sampled in 9 sites).

Examples of biodiversity patterns as function of the spatial scale are shown in Figures 6 for syrphids and 7 for carabids, the two groups that clearly showed this trend. Contrarily butterflies and sawflies did not seem to be influenced by the landscape structure. Butterflies are more likely influenced by the micro-habitat characteristics, including the vegetation characteristics and types and also probably the micro-climate (Tables 1, 3 and 4). These conclusions are corroborated by the correspondence analysis (Figure 8), which shows that syrphids are strongly associated with landscapes characterised by a high complexity, and carabids are correlated with landscapes characterised by a high complexity and, in a lesser extent, with landscapes with intermediate complexity. Butterflies, on the contrary, are strongly influenced by the weedy margins and they seem to be independent of landscape complexity (Figure 8). Syrphid populations are further strictly associated with the vegetations that have hedgerows (Figure 8).

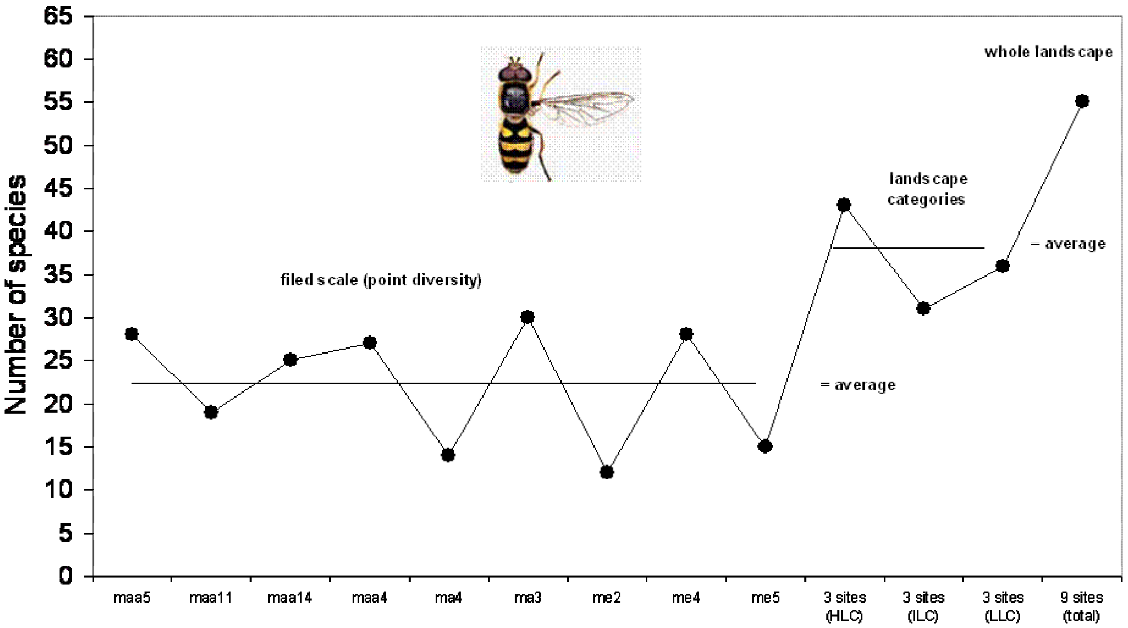

Figure 6. Number of syrphid species as function of the scale of monitoring. The field scale diversity is represented by the species sampled in each site (9 sites). The landscape category scale is represented by the species sampled in each landscape category (3 sites). The whole landscape scale is represented by the species sampled at all the sites. HLC = high landscape complexity; ILC = intermediate landscape complexity; LLC = low landscape complexity.

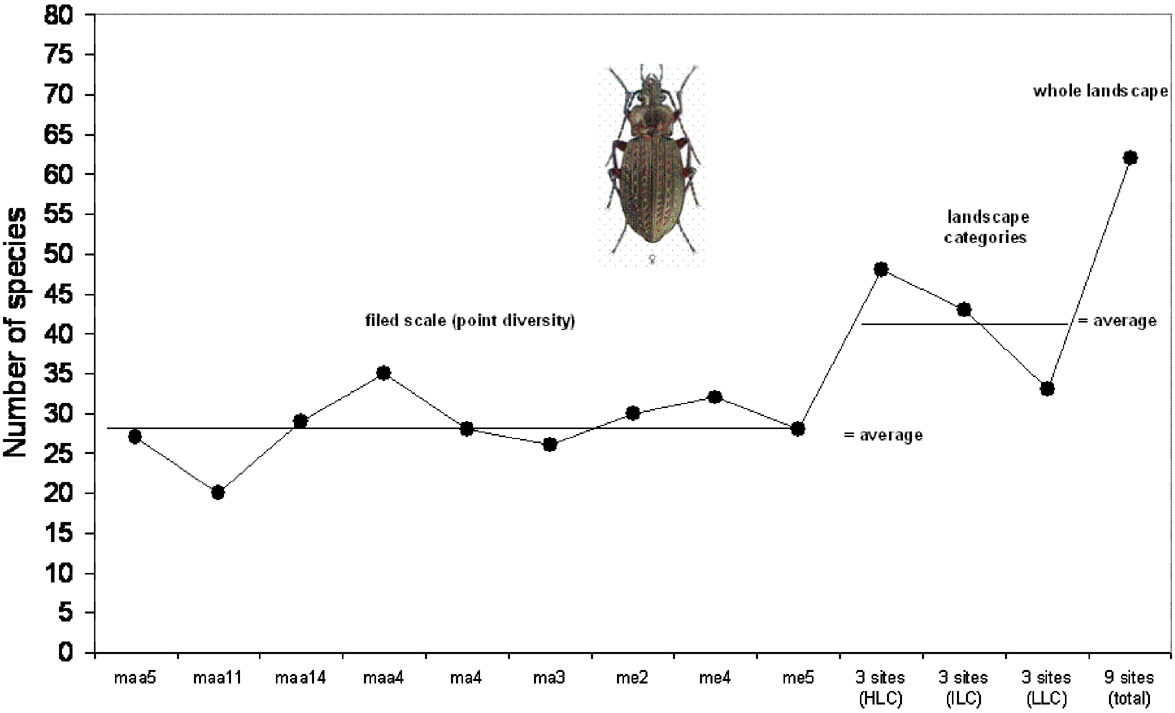

Figure 7. Number of Carabid species as function of the scale of monitoring. See Figure 6 for explanation.

Table 4. Number of insect species as function of the landscape categories and vegetation types. The landscape categories and the vegetation types are described in chapter 7.

	# species sampled			
	syrphids	carabids	butterflies	sawflies
Landscape categories				
High complexity	43	48	34	24
Intermediate complexity	31	43	32	16
Low complexity	36	33	36	32
Vegetation types				
Hedgerow with abundant grass and flower strips	47	37	36	34
Hedgerow with small grass strips	39	45	28	17
Weedy margins	31	41	31	14

The position of sawflies is more controversial, although this group is related to vegetation types characterised as “hedgerows with abundant flowers and grass strips”, and it seems to be independent of landscape characteristics (Figure 8). Sawflies depend for their larval requirements on the presence of host plants. For this reason, populations and species richness reflects the vegetation richness and type, and in general the microhabitat characteristics. It is remarkable that the highest sawflies diversity and abundance were recorded in a site (Maa14) characterised by the highest plant and butterfly richness. This site showed also a good value of “biodiversity maintenance function” *sensu* Speight and Castella

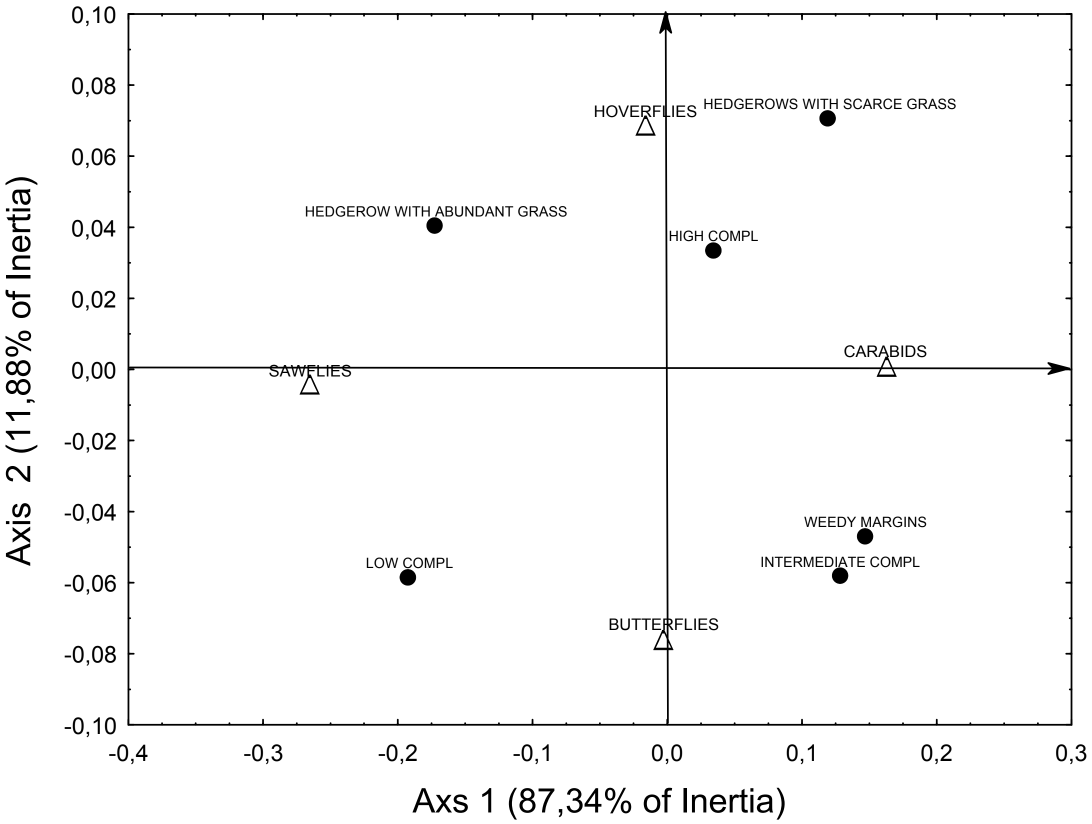

Figure 8. Correspondence analysis, showing the ordination of the insect relative abundances in relation to the landscape/vegetation types.

(2001) and Speight et al. (2002) (see “Syrph the Net” analysis employed in chapter 7). The special character of this micro-habitat is confirmed by the PCA calculated on the sawflies species-abundances matrix, which shows that site Maa14 is isolated from the other sites (Figure 9). The influence of vegetation type on butterfly abundance is shown in Figure 10. The figure shows that catch frequencies are highest on weedy margins, followed by “«hedgerow with grass and wild flower strip” and “hedgerows scarce grass strips”. Also PCA performed on the matrix of butterfly species and abundances clusters the sites mainly according the vegetation types. The sites with “grass and wild flower strips” (weedy margins) are grouped together and clearly separated from the other vegetation typologies (Figure 11).

Faunistic analysis of insect fauna and flora

The lists of insect and plant species sampled, including the total relative abundances at the nine sites are reported in the appendix. These check lists can be considered as a faunistic and floral inventory of the insects and plants studied, and are thus contributing to a data-base for flora and fauna conservation. The check lists can also be used in further studies on the impact of the rural practices on plant and animal communities and to monitor the conservation status of biodiversity in this rural landscape over time. A analysis of each insect group and of the plants is reported below.

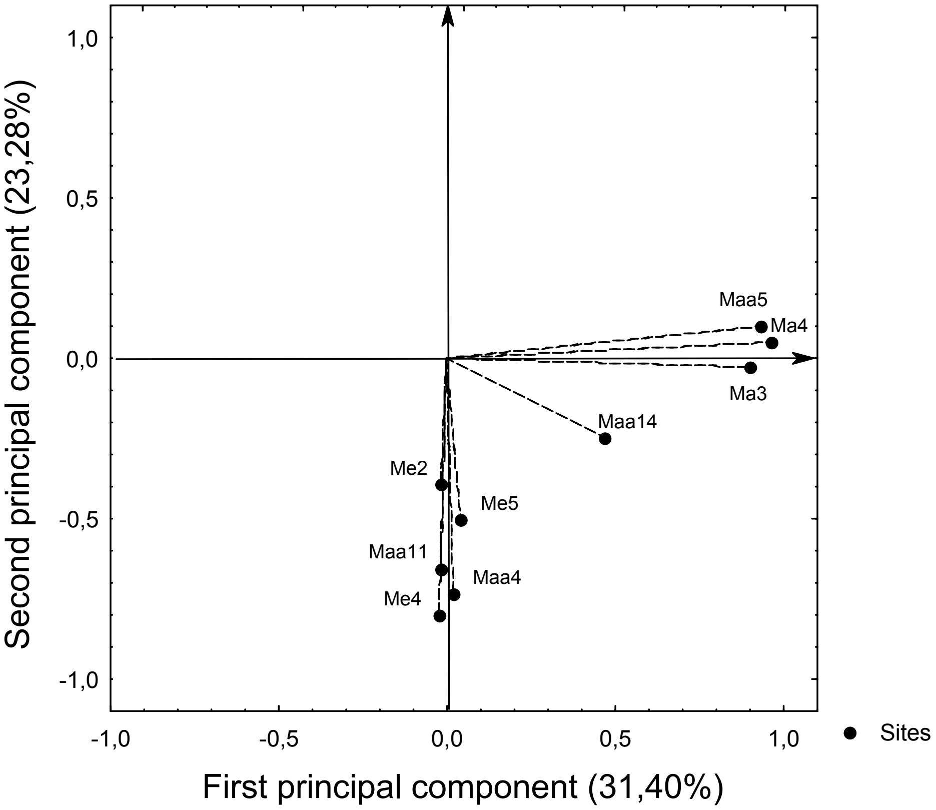

Figure 9. Ordination of the sites on the basis of the Symphyta fauna.

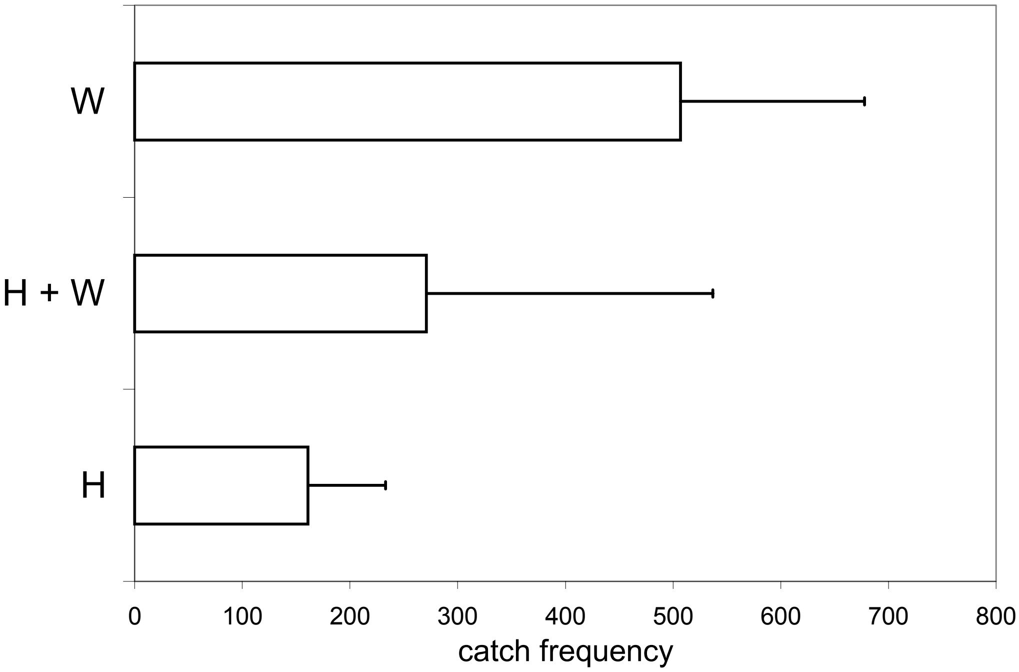

Figure 10. Butterfly catch frequencies in relation to the vegetation types. W = Grass and wild flower strip (weedy margins); H + W = Hedgerow with grass and wild flower strip; H = Hedgerow with small grass strip.

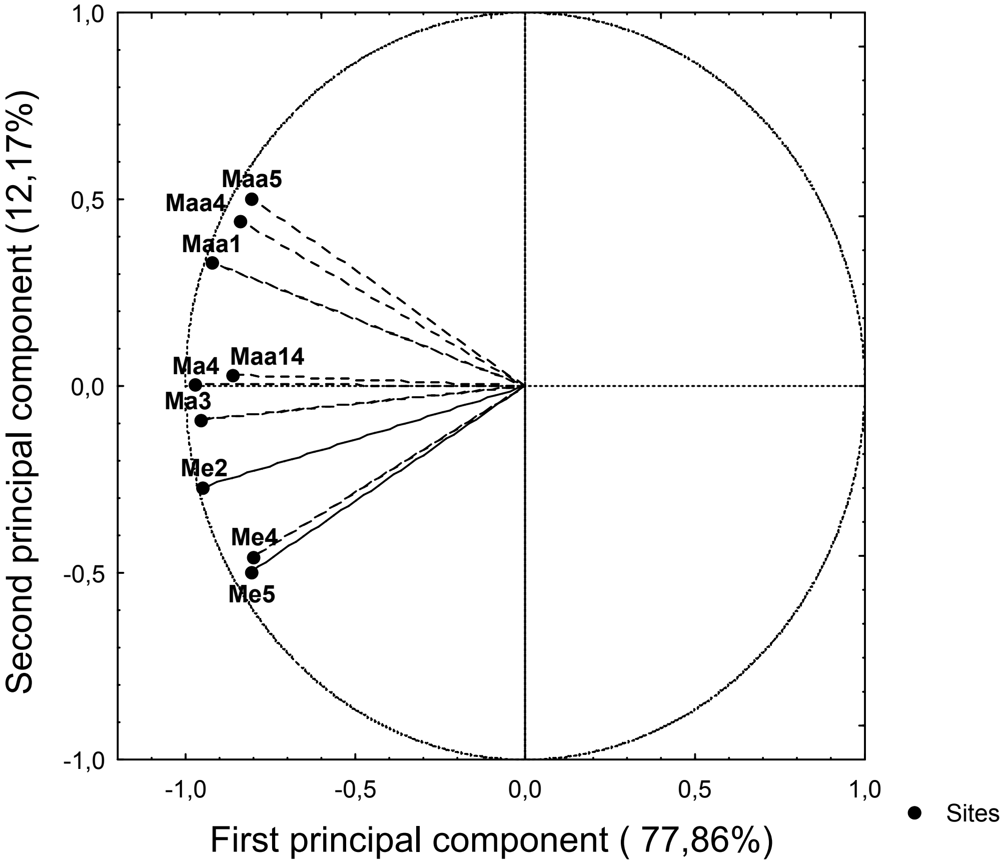

Figure 11. Ordination of the sites on the basis of the butterfly fauna.

Butterflies

A total of 39 butterfly species was found. The most abundant species were *Polyommatus icarus* (23% of the catches), *Coenonympha pamphilus* (20%) and *Pieris rapae* (11%) (Table 1-bis, chapter 8 appendix). These species accounted together for 54% of the catches. *P. icarus* is one of the commonest species in Italian rural landscapes. The three commonest species are characterised by a wide host range, including common plant species that are abundant in rural landscapes. In a similar study, Fabbri and Scaravelli (2002) sampled the butterfly fauna that inhabited hedgerows of biological farms in northern Italy, and recorded a total of 21 species. These authors found that farms with the lowest values of lepidopteran diversity had hedgerows and bordering fields that were seriously disturbed by repeated mowing and a higher chemical input from neighbouring crops.

Some of the species we sampled in the research are considered rare in rural landscapes of the Emilia-Romagna region and are marked with an asterisk in Table 5 (Marini, 1981 and 1998; Fiumi and Camporesi, 1998; Chiavetta, 1998 and 2000; Govi and Fiumi, 1998). Their rareness is the result of habitat destruction and disturbance of the non-crop areas as well. Also *Pieris edusa* is not common in rural agroecosystems (Fiumi and Camporesi, 1988; Merighi, 2000; Fabbri and Scaravelli, 2002). *Iphiclides podalirius* is linked to shrubs and trees within hedgerows. Other species that Fiumi and Camporesi (1991) found linked to hedgerows, like *Aporia crataegi*, *Nymphalis antiopa*, *N. polychloros* and *Limenitis reducta*, were not found in

Table 5. Mean total abundances of insects, calculated by means of the total specimens collected per trap (syrphids and sawlies), the total mean density activity (=total of specimens per trap and sampling data)(carabids) and the total frequency of catches (butterflies).

Sites	Syrphidae abundance	Carabidae abundance	Symphyta abundance	Butterflies abundance
Maa5	523	11,53	62	285
Maa11	248	9,6	15	225
Maa14	348	35,71	80	892
Maa4	645	53,06	24	171
Ma4	148	16	22	428
Ma3	608	79,15	21	459
Me2	113	25,42	4	621
Me4	551	22,23	30	1162
Me5	186	32,71	10	885

our study. In our research hand net sampling was carried out, using the catch and release method. Collection of adults was employed only in cases of uncertain adult identification. This methodology showed to be suitable for sampling the rural landscape, and has a low ecological impact because the butterflies are released after identification. But this sampling method is not quantitative and can be applied only for relative comparisons among the frequencies of catches at sites, to calculate relative abundances of the species collected, and in general for a faunistic analysis of butterflies.

In a study carried out at 10 arable sites in Cambridgeshire (UK) a total of 22 butterfly species were recorded and, with the exception of one rare species, they were most abundant in the green lanes in comparison with other types of linear features (Croxton *et al.*, 2004). In the mentioned study species richness of butterflies was positively associated with species richness of the plants and with the number of larval food plants of these butterflies. The preference of butterflies for green lanes might be the result of their greater diversity of plant species, the greater abundance of larval food plants, the more sheltered conditions and the greater structural variety. The results of Croxton *et al.* (2004) are comparable with those of our study because the green lanes of the UK study show great affinity with our “hedgerow and weeds” plant typology. Linear landscape features have been recognised as providing a wide range of functions for a variety of wildlife, including butterflies (Dover *et al.*, 1999; Sparks *et al.*, 1999; Croxton *et al.*, 2004). They act as linkages between habitats, roost and shelter sites and provide plant diversity (Croxton *et al.*, 2004).

Carabid beetles

Sixty-two carabid species totalling 8554 individuals were sampled at seven samplings between April and November of the three years (Table 2-bis, chapter 8 appendix). Species richness was correlated with sample size (Figure 12) for each sample. The fitted curve seems to approach a maximum value, which confirms the consistency of our sampling. The most abundant carabid was *Steropus melas italicus* (26.5%), a predator species common in rural landscapes, followed by *Brachinus psophia* (10.7%), *Calathus fuscipes latus* (10.3%), *Anchomenus dorsalis* (9.1%) and *Poecilus cupreus* (8.1%). These five species accounted for

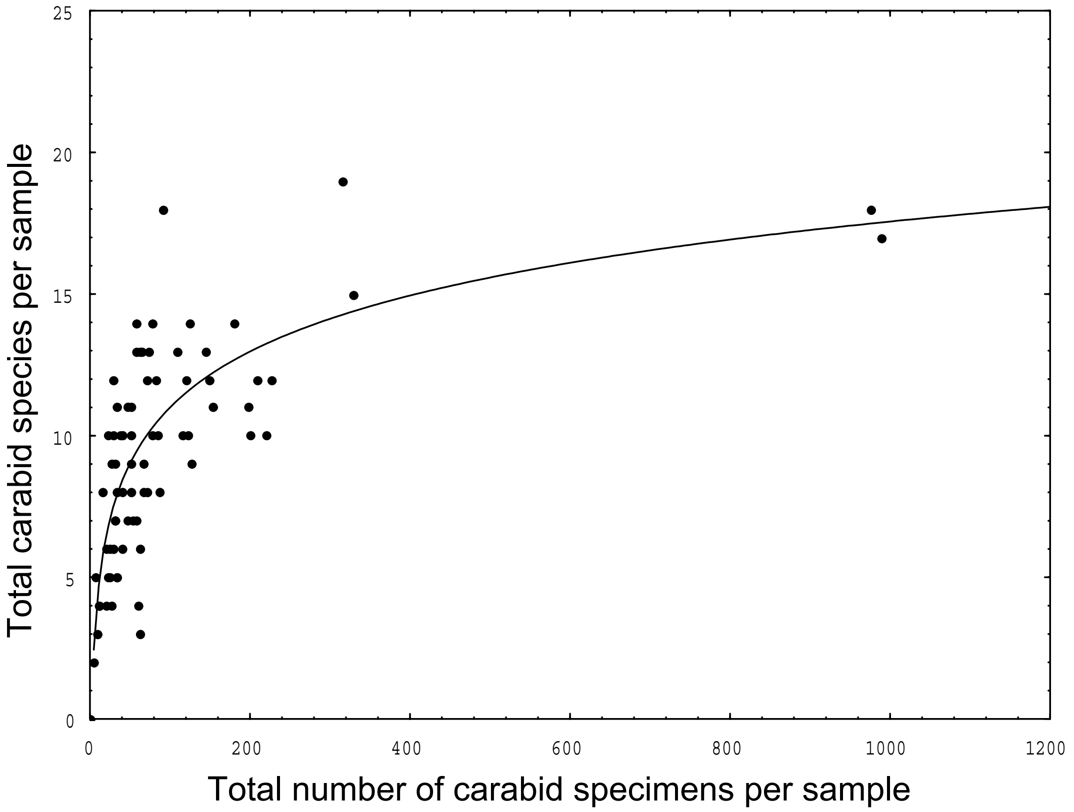

Figure 12. Relationship between the sample size (number of carabid individuals per sample) and the species richness (number of carabid species per sample). R = 0.75, P<0.01.

64.8% of the carabid abundance. Twelve species accounted for 90.8% of the carabids found. Fifty species had a relative abundance of less than 1%. The most abundant species are quite common in the rural landscape, field margins and open natural environments. As the common and large species can move further and often faster than the smaller ones, they generally dominate much of the catch, especially in agricultural habitats (Luff, 2000). Several of the less abundant species are recorded for the first time in Emilia-Romagna (*Ophonus melleti*, *Anisodactylus signatus*, *Leistus ferrugineus*, *Zuphium olens*, *Agonum permoestum, Lamprias cyanocephala*, *Ophonus diffinis*, and *Harpalophonus italicus*) (Fabbri, personal communication). Rare species like *O. melleti, O. diffinis and H. italicus* are typical of hilly habitats, but can move toward the flat rural areas when there are ecological corridors (Fabbri, personal communication).

Biology and ecology of carabid fauna in rural landscapes has been extensively reviewed (e.g. Kromp, 1999; Holland, 2002). The number of species is one of the most important parameters to characterise any environment and these kind of data are available for environments worldwide. The number of carabid species sampled depend on many factors, including the sampling effort, the number of traps used and the exposure time of traps (Luff, 2002). Estimated total richness curves all suggest the total species richness at a site to be about 32-33 species and that between 20 and 30 samples would be sufficient to obtain this total (Luff, 2002). Luff (2002) summarizes data from 199 published lists of carabids from individual field/season combinations worldwide. The mean species richness in all regions is just below 30 species for a site/field, despite the considerable range of species richness from one list to another within regions. The literature also shows that the five dominant species usually comprise nearly 85% of the catch, and that 10 species comprise 95% or more of the carabid fauna (Luff, 2002). These data are in agreement with our study. When we compare our data with those of other agricultural areas, the carabid richness in our study (62 species) is very high. This is probably reflecting the spatial scale of our investigation and the effect of the ecological infrastructures adjacent to the pit-fall traps.

Syrphids

A detailed analysis of the syrphid fauna is reported in chapter 7, including comments on the species sampled and an ecological analysis by means of “Syrph the Net”. In this chapter only the syrphid species sampled by means of Malaise traps - the most effective sampling technique and considered the standard method to sample this group - are shown and a species list is reported in appendix (Table 3-bis). Only three species accounted for the 75.5% of the species abundance. These very common species (*Melanostoma mellinum*, *Sphaerophoria scripta* and *Episyrphus balteatus*) are typical of rural environments and are considered important predators of insect pests, including aphids (Sommaggio, 1999). Five species with a relative abundance between 1 and 5% accounted for the remaining 14.9% of the catches. Finally, 47 species were characterised by a relative abundance less than 1%. *Paragus hyalopteri* is a new record for the Italian fauna, and recently this species has been recorded in another Italian locality (Sommaggio, personal communication).

In only a few studies syrphids have been used as bioindicators of cultivated areas in Italy, and these studies focussed mainly on infrastructure conservation within the rural landscape (reviewed by Burgio and Sommaggio, 2002 and Sommaggio and Burgio, 2004). Speight et al. (2002), in a study of on farm syrphid faunas under various management regimes, found 32 species in «productive habitats», 47 species in «infrastructure habitats» and 55 species in «disused habitats». Although it is always difficult to compare data of studies done in different geographic areas (the cited study of Speight was employed in Ireland), and of studies characterised by differences in sampling methods (in the study of Speight Malaise trap sampling was integrated with hand net and emergence traps), the syrphid diversity in our research seems to be considerable, including the presence of rare species. The landscape diversity of syrphids in our study shows a total of 55 species with a site diversity ranging from 14 to 30 species.

Sawflies

A total of 191 specimens was sampled, representing 41 species. *Nematus lucidus* (23.88%) was the most abundant species, followed by *Priophorus rufipes* (7.84%) and *Loderus vestigialis* (10,47 %) (Table 4-bis, chapter 8 appendix). These three species together represent about the 40% of the total of the specimens collected. Besides commons species, also some rare species were collected. For example, *Caliroa cothurnata* was for the first time recorded in Italy, but the status of this species is not clear (Pesarini, personal communication). For their larval requirements, many sawlies species are dependent to one or a few plant species. For this reason, sawflies are strictly linked to the type of vegetation of a site. In the selection of insects for use as bio-indicators in nature conservation research in Ireland, sawflies were considered as foundation group (Speight, 1986). A disadvantage for the use of sawflies as bioindicators is their limited representation in the literature. Very few data are available on sawflies in rural landscapes in Italy and this paper is one of the first contributing to this topic.

Plant communities

Some rare plant species for our region were found, like *Fraxinus oxycarpa, Stachys palustris, Inula helenium, Euphorbia esula, Abutilon teophrasti, Barbarea vulgaris, Clematis viticella, Clematis flammula, Bellevalia romana, Euphorbia exigua* and in particular *Leucojum aestivum*. These plants are protected in our region. Moreover, other interesting plant species were found, like *Aristolochia rotunda* and *Aristolochia clematitis,* larval food plants for the butterfly *Zerynthia polyxena.*

Conclusions

In this study a consistent spatial scale-effect on insect and plant biodiversity was found. The species richness of some groups (i.e. syrphids and carabids) significantly increases from site scale, via the meso-scale (the species richness in each landscape category) to the landscape scale (total of species sampled for the whole landscape). The need to carry out insect and plant sampling programs on a landscape scale is an extra complication for landscape management disciplines, but is necessary for functional biodiversity evaluations.

Our research demonstrates that each insect group displays different biodiversity patterns in relation to the different landscape/micro-habitat categories. Some groups provided reliable information about diversity at landscape scale, while others were better diversity indicators at micro-habitat scale. So it is important to select a suitable indicator for the specific scale of interest or of the specific aim of study. For example, in this study a positive effect of the landscape structure and complexity was found only for syrphids and carabids, while other groups like butterflies and sawflies were stronger affected by the micro-habitat characteristics. For environmental analysis and for the evaluation of the intrinsic quality of agro-environmental measures, a multidisciplinary approach is needed for optimal discrimination of the different solutions. Further, in a ”functional biodiversity approach”, it is important to study the conservation status of rare species and to address the suitable management interventions in order to save biota that are at extinction risk. Such an ethic approach should take into account the aspect of extinction, which should preferably also be included in the practical discipline of landscape management.

Syrphids seem to be good rural landscape indicators, which confirms the conclusion expressed in chapter 7. This group also showed to some extent sensitivity to micro-habitat characteristics, but this can be analysed and explained much better by the “Syrph the Net” method (see chapter 7). The power of syrphids as functional bioindicators is explained by the heterogeneity of the trophic larval requirements. Moreover, the larvae of many species are important insect predators and for this reason syrphids are considered crucial in conservation biological control. Also carabids seem to be affected by landscape complexity, but to a lesser extent than syrphids. Carabid richness and abundance are not clearly explained by the vegetation characteristics. Butterflies seem to be poor landscape bioindicators for northern Italian rural landscapes, because of their biological and ecological characteristics, including the high mobility of adults and strong dependence of specific micro-habitats. Plant typology of the micro-habitat greatly determined the richness of butterflies, and presence of specific micro-habitats is crucial for butterfly conservation, including rare species. This explains why the richness of butterflies in our study was strongly affected by occurrence of certain micro-habitats at the sites and not by the structural complexity around the sites. The sawflies are poorly investigated in northern Italy, as well as in other European rural habitats. Their diversity pattern drastically changes in relation to the different sites and their diversity is correlated with that of syrphids. Therefore, sawflies seem good micro-habitat indicators, but further studies are needed in different rural contexts before they can generally be used as reliable indicators.

Finally, it is important to give a "functional meaning" to faunistic lists of insects in a "landscape management approach". To be able to develop this functional meaning, it is crucial to develop relevant tools for quantitative and faunistic analyses of data. Tools like Syrph the Net (Speight et al., 2001; chapter 7 of this thesis) provide the methodology to determine the quality of the environments in a standard way, and help to explain the functional relathionships among rural landscape, micro-habitats and biodiversity and a meaningful way.

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Appendix

Table 1bis. List of the butterfly species (% = relative abundances) sampled by means of hand net and visual-inspection.

Species	%
Polyommatus icarus (Rottemburg)	23,07
Coenonympha pamphilus (L.)	20,12
Pieris rapae (L.)	10,92
Plebejus argus (L.)	5,52
Colias crocea (Geoffroy)	5,13
Thymelicus lineolus (Ochsenheimer)	3,84
Melitaea didyma (Esper)	3,51
Leptotes pirithous (L.)	2,79
Inachis io (L.)	2,57
Lasiommata megera (L.)	2,40
Melitaea athalia (Rottemburg)	2,09
Vanessa cardui (L.)	1,93
Pararge aegeria (L.)	1,64
Vanessa atalanta (L.)	1,58
Ochlodes venatus (Bremer et Grey)	1,42
Lycaena phlaeas (L.)	1,31
Polygonia c-album (L.)	1,31
Melitaea phoebe (Goeze)	1,01
Cupido argiades (Pallas)	0,94
Aricia agestis (Denis et Schiffermuller)	0,90
Pyrgus malvoides (Elwes et Edwards)	0,90
Iphiclides podalirius (L.)	0,80
Lycaena dispar (Haworth)	0,60
Colias hyale (L.)	0,59
Pieris napi (L.)	0,55
Pieris brassicae (L.)	0,53
Erynnis tages (L.)	0,43
Papilio machaon L.	0,39
Apatura ilia (Denis et Schiffermuller)	0,23
Lycaeides idas (L.)	0,23
Pieris edusa (F.)	0,23
Lycaena tityrus (Poda)	0,18
Carcharodus alceae (Esper)	0,16
Argynnis paphia (L.)	0,04
Celastrina argiolus (L.)	0,04
Lasiommata maera (L.)	0,04
Spialia sertorius (Hoffmannsegg)	0,04
Lampides boeticus (L.)	0,02
Zerynthia polyxena (Denis et Schiffermuller)	0,02

Table 2bis. List of the carabid beetles species (% = relative abundances) sampled by means of pit-fall traps.

Species	%	Species	%
Steropus melas italicus (Dejean)	26,56	*Microlestes fulvibasis* (Reitter)	0,15
Brachinus psophia Serville	10,76	*Badister bullatus* (Schrank)	0,13
Calathus fuscipes latus Serville	10,33	*Ophonus puncticeps* Stephens	0,07
Anchomenus dorsalis (Pontoppidan, 1763)	9,17	*Brachinus ganglbaueri* Apfelbeck	0,06
Poecilus cupreus (L.)	8,01	*Apotomus rufus* (Rossi)	0,05
Brachinus crepitans (L.)	6,93	*Panagaeus cruxmajor* (L.)	0,05
Pseudophonus rufipes (Degeer)	6,56	*Anisodactylus signatus* (Panzer)	0,04
Trechus quadristriatus (Schrank)	4,50	*Leistus ferrugineus* (L.)	0,04
Harpalus dimidiatus (Rossi)	4,30	*Zuphium olens* (Rossi)	0,04
Harpalus distinguendus (Duftschmid)	1,72	*Campalita maderae* (F.)	0,03
Brachinus plagiatus Reiche	1,06	*Amara aenea* (Degeer)	0,03
Ophonus ardosiacus (Lutshnik)	1,01	*Callistus lunatus* (F.)	0,03
Harpalus flavicornis Dejean	0,87	*Harpalus anxius* (Duftschmid)	0,03
Brachinus sclopeta (Fabricius)	0,72	*Parophonus hispanus* (Rambur)	0,03
Platysma nigrum (Schaller)	0,66	*Phonias strenuus* (Panzer)	0,03
Harpalus oblitus Dejean	0,65	*Agonum permoestum* Puel	0,02
Diachromus germanus (L.)	0,63	*Carabus granulatus interstitialis* Duft	0,02
Dinodes decipiens (Dufour)	0,61	*Amara similata* (Gyllenhal)	0,01
Scybalicus oblongiusculus (Dejean)	0,52	*Lebia humeralis* Dejean	0,01
Harpalus tardus (Panzer)	0,51	*Microlestes minutulus* (Goeze)	0,01
Ophonus azureus (F.)	0,48	*Paradromius linearis* (Olivier)	0,01
Platysma melanarium (Illiger)	0,40	*Ophonus diffinis* (Dejean)	0,01
Ophonus melleti (Heer)	0,34	*Asaphidion flavipes* (L.)	0,01
Parophonus mendax (Rossi)	0,32	*Asaphidion stierlini* (Heyden)	0,01
Microlestes maurus (Sturm)	0,24	*Chlaeniellus vestitus* (Paykull)	0,01
Gynandromorphus etruscus (Quensel)	0,22	*Harpalophonus italus* (Schaum)	0,01
Microlestes corticalis (Dufour)	0,21	*Harpalus pygmaeus* Dejean	0,01
Amara familiaris (Duftschmid)	0,19	*Lebia scapularis* (Fourcroy)	0,01
Syntomus obscuroguttatus (Duftschmid)	0,17	*Parophonus maculicornis* (Duftschmid)	0,01
Platysma macrum (Marsham)	0,17	*Parophonus planicollis* (Dejean)	0,01
Philochthus lunulatus (Fourcroy)	0,15	*Stomis pumicatus* (Panzer)	0,01

Table 3bis. List of the syrphid species sampled by means of Malaise traps and sticky yellow traps. The list reports the total of species sampled in chapter 7. See chapter 7 for the relative abundances of species sampled with the different sampling techniques.

Species	Species
Anasimyia contracta Claussen & Thorp	*Melanostoma mellinum* (L.)
Anasimyia transfuga (L.)	*Melanostoma scalare* (F.)
Brachyopa scutellaris Robineau-Desvoidy	*Meliscaeva auricollis* (Meigen)
Ceriana conopsoides (L.)	*Merodon avidus* (Rossi)
Chalcosyrphus nemorum (F.)	*Mesembrius peregrinus* (Loew)
Cheilosia intonsa Loew	*Myathropa florea* (L.)
Cheilosia ranunculi Doczkal	*Neoascia interrupta* (Meigen)
Chrysotoxum cautum (Harris)	*Neoascia podagrica* (F.)
Epistrophe eligans (Harris)	*Neoascia tenur* (Harris)
Epistrophe nitidicollis (Meigen)	*Paragus bicolor* (F.)
Episyrphus balteatus (de Geer)	*Paragus bradescui* Stanescu
Eristalis arbustorum (L.)	*Paragus haemorrhous* Meigen
Eristalis pertinax (Scopoli)	*Paragus hyalopteri* Marcos-Garcia & Rojo
Eristalis similis (Fallen)	*Paragus pecchiolii* Rondani
Eristalis tenax (L.)	*Paragus quadrifasciatus* Meigen
Eristalinus aeneus (Scopoli)	*Parhelophilus versicolor* (F.)
Eristalinus sepulchralis (L.)	*Pipizella maculipennis* (Meigen)
Eumerus amoenus Loew	*Pipizella viduata* (L.)
Eumerus argyropus Loew	*Platycheirus fulviventris* (Macquart)
Eumerus sogdianus Stackelberg	*Scaeva pyrastri* (L.)
Eumerus strigatus (Fallen)	*Sphaerophoria rueppellii* Wiedemann
Eupeodes corollae (F.)	*Sphaerophoria scripta* (L.)
Eupeodes latifasciatus (Macquart)	*Syritta flaviventris* Macquart
Eupeodes latilunulatus (Collin)	*Syritta pipiens* (L.)
Eupeodes luniger (Meigen)	*Syrphus ribesii* (L.)
Helophilus pendulus (L.)	*Syrphus torvus* Osten-Sacken
Helophilus trivittatus (F.)	*Syrphus vitripennis* Meigen
Heringia brevidens (Egger)	*Triglyphus primus* Loew
Heringia verrucula (Collin)	*Xanthogramma pedissequum* (Harris)
Lejogaster tarsata (Megerle in Meigen)	*Volucella zonaria* (Poda)

Table 4bis. List of the sawflies species (%= relative abundances) sampled by means of Malaise traps.

Species	%
Nematus lucidus (Panzer)	23,88
Priophorus rufipes (Serville)	7,84
Loderus vestigialis ((Klug)	7,46
Sterictiphora angelicae (Panzer)	6,72
Athalia cordata Serville	5,60
Cladius pectinicornis (Geoffroy)	4,85
Emphytus calceatus (Klug)	4,85
Macrophya annulata (Geoffroy)	4,48
Halidamia affinis (Fallén)	4,10
Macrophya alboannulata Costa	3,73
Nematus myosotidis F.	2,24
Tenthredopsis cf *dubia* Konow	1,87
Monophadnoides rufricruris (Brullé)	1,87
Loderus evesmanni (Kirby)	1,49
Pareophora pruni (L.)	1,49
Pristiphora conjugata (Dahlbom)	1,49
Athalia rosae (L.)	1,12
Cladardis elongatula (Klug)	1,12
Empria excisa (Thomson)	1,12
Endelomyia aethiops (Gmelin)	1,12
Metallus pumilus (Klug)	1,12
Stauronematus compressicornis (F.)	1,12
Arge cyanochrocea (Forster)	0,75
Caliroa varipes (Klug)	0,75
Pamphiliinae	0,75
Monostegia abdominalis (F.)	0,75
Rhogogaster viridis (L.)	0,75
Taxonus agrorum (Fallén)	0,75
Aglaostigma aucupariae (Klug)	0,37
Athalia circularis (Klug)	0,37
Athalia liberta (Klug)	0,37
Stethomostus fulliginosus (Schrank)	0,37
Cladius difformis (Panzer)	0,37
Dolerus germanicus (F.)	0,37
Dolerus haematodes (Schrank)	0,37
Caliroa cothurnata (Serville)	0,37
Pontania sp.	0,37
Priophorus brullei Dahlbom	0,37
Pristiphora aphantoneura (Forster)	0,37
Pristiphora pallidiventris (Fallén)	0,37
Tenthredo zonula Klug	0,37

Chapter 9

Summarising discussion

Introduction

The study of biodiversity shows similarities to that of quantum mechanics: there is a much talk about these studies, but probably few scientists have a clear idea about the real meaning of these disciplines. Quantum mechanics provided important solutions to various problems in sciences such as chemistry and physics. Concepts of biodiversity were only developed by the scientific community when people realized that many species on our planet were at risk of extinction, or were already extinct, because of the destruction by man of many biotopes. In other words, biodiversity became a science issue not at the moment that scientists understood the concept of diversity, but when scientists and many others realized that biological diversity was a common good to be defended.

Agriculture strongly contributed to the loss of biodiversity and, recently, sustainable agricultural production systems have been developed with the aim to contribute in "curing" the planet. Such sustainable production systems changed the paradigm of crop production.

Many difficulties in the debate involving the biodiversity concept lie in the fact that not only scientific, but also social and ethical aspects occur in its definition. Within the complex context of the biodiversity concept, I limited myself to an explanation of the different aspects of biological variation. In the thesis, I focused mainly on a specific aspect of biodiversity, functional biodiversity, which is considered an important tool in multifunctional agriculture. For this reason, I did not try to further develop the meaning and the theoretical aspects of the biodiversity. Instead, I have tried to contribute to insight in how conservation of beneficial fauna may help improving biological control of insect pests, while at the same time developing knowledge on how to conserve rare insect species within the rural landscape. The latter topic is an important but still neglected aspect in applied entomology. Recently, crucial progress in the biodiversity debate was made when scientists developed the idea that biodiversity studies could create solutions to improve the quality of the planet and human life. In this context, my thesis contributes more to "what biodiversity may contribute to safe species" than to "what biodiversity means".

In **Chapter 1** I consider practical aspects of biodiversity conservation in the light of the disciplines which postulate that biodiversity conservation and enhancement may contribute important ecological services to rural farms. I approached the problem of biodiversity conservation with the assumption to improve the quality of the rural environment. I started from the consideration that enhancing plant and animal diversity has become an aim of agricultural policy in various countries. I reviewed the insect conservation theory in the light of the importance in conservation biological control, focusing mainly on the contribution of natural enemies from non-crop habitats to biological control of pests in agroecosystems. Then, I briefly summarised the main characteristics of my study-area, the rural landscape of the Po Valley in northern Italy. In particular, I focused on the agro-environmental schemes used in the Emilia-Romagna region, which has changed the rural landscape structure and quality during the past 15 years, by means of conservation and restoration of ecological infrastructures and natural habitats (or ecological compensation areas = ECAs). Conservation and restoration of ECAs in Emilia-Romagna have resulted in a strong reduction of chemical inputs such as pesticides. Because habitat destruction and fragmentation are considered to be the major negative factor in reducing species numbers and thus of biodiversity, I focused on the importance of linking the biodiversity within habitats (local biodiversity) to the biodiversity within the landscape (regional biodiversity). Characteristics of rural landscapes and biodiversity patterns may vary considerably in relation to geographic area, climatic condition, crop system, farm and landscape management, and pest management strategies. For these reasons it is crucial to collect information starting at the "local scale", because the role of functional biodiversity and landscape management on conservation biological control cannot be generalized at higher scales. In this context sampling of insect biodiversity at field/farm scale is an important step to study the multitrophic relationships among "plants-herbivorous insects - carnivorous insects" in order to select suitable plants and management techniques to enhance conservation biological control of insect pests. I found that many studies are available for this scale of observation, but these often lack the identification of reliable bio-indicators. If one intends to improve the quality of the rural landscape, it is essential to select effective bio-indicators to be able to determine the effects of habitat management on the quality of rural environment at higher scales, such as the landscape. Therefore, I stressed in the final part of chapter 1 the importance of increasing the spatial scale of observation from farm to landscape, to be able to link local to landscape biodiversity patterns. This change in spatial scale is also important in the selection of proper bioindicators at the specific scale of study and to evaluate the effect of habitat management on the macro-scale.

Function of farm scale ecological infrastructures for generalist predators

The thesis comprises three case-studies, each discussed in a separate section. In the first section I discuss the role of functions of ecological infrastructures with respect to predator populations, with particular attention to coccinellids. Coccinellids play a crucial role in conservation biological control in Emilia-Romagna. In **chapter 2,** I report about the role of shrubs, trees and weeds on the multiplication and life cycles of beneficial predators. I also provide a detailed list of plants and related predators. Particular attention was given to Coleoptera Coccinellidae because of their importance in controlling aphid populations on many crops in northern Italy. Data showed that coccinellids were the dominant group among predators sampled in ECAs, and the aphidophagous species were the dominant group within the coccinellids. The commonest coccinellid species on trees and shrubs was *Adalia bipunctata,* while on weeds the most abundant species was *Hippodamia variegata*. Mechanical knock-down sampling and visual inspection demonstrated that plants within hedgerows can supply both multiplication sites and shelters for predatory coccinellids. Particularly trees and shrubs provided shelter for adult ladybirds mainly in late summer-early autumn, a period in which many arable crops in the Emilia-Romagna region are harvested. Besides this shelter function, all the trees and shrubs provided multiplication sites for coccinellids, with the exception of *Sambucus nigra*. Among the trees and shrubs, *Euonymus europaeus* and *Prunus spinosa* showed the highest level of predator biodiversity. Among the weeds, *Cirsium*, *Rumex* and *Urtica dioica* supported the multiplication of ladybirds. On the other hand, other common weed species (i.e. *Daucus carota*, *Amaranthus retroflexus*, *Dipsacus sylvestris*, *Arctium* sp., *Crepis* sp. and *Picris* sp.) provided shelters for coccinellids. Adult density of *H. variegata* on *D. carota* reached a peak between August and September, a period in which many crops are harvested. The sampling data also demonstrated that adults of the coccinellid *H. variegata* took shelter inside the flowers of *D. carota*. Adults were observed feeding on pollen, confirming that pollen can supply secondary food for aphidophagous predators. The work described in **chapter 2**, illustrates the importance of the right sampling techniques to study biodiversity. For example, the mechanical knock-down method was more effective than visual inspections to sample coccinellids on trees and shrubs. Mechanical knock-down was particularly suitable to sample coccinellid species belonging to the Scymnini tribe, and these were always underestimated by visual sampling. In addition to providing multiplication sites for coccinellids, a group of ten plant species, including trees, shrubs and weeds (see the lists in **chapter 2**) provided multiplication sites for Syrphidae, while thirteen plant species supported multiplication of Neuroptera Chrysopidae. Finally, *Demetrias atricapillus*, a species common on trees, was the only predatory carabid species collected on hedgerows.

While the approach in **chapter 2** is mainly faunistic, in **chapter 3**, attention is given to the insect predator complex on weedy margins adjacent to crops, in order to understand the population dynamics of generalist predators. I found that field margins adjacent to ecological corridors are essential for the cyclic movement of predators from weeds to crop and *viceversa*. Coccinellids and, interestingly, nabids (Rhynchota), were the most abundant groups. *Hippodamia variegata* was the most abundant coccinellid species, confirming the results obtained in the previous chapter. A high population of *Anthocoris* sp. was recorded at one site only. Nabids were the most abundant insects within margins adjacent to old hedgerows, which showed generally a more uniform distribution of relative abundance of predators than young hedgerows. On the other hand, the weedy margins adjacent to young hedgerows were characterised by a strong predominance of coccinellids. The age of adjacent hedgerows and the intensity of ECA management may have influenced the abundance and dominance of predator populations. The different ECA management strategies could be one of the causes of the different nabid assemblages. Management of transects near young hedgerows was more intensive than those of old ones, thus contributing to a change in this predator group. Only one site, characterised by strong dominance of anthocorid predators, formed a separate group, and this was probably due to the influence of an adjacent pear orchard. Sweep net sampling was particularly suitable in order to study the phenology of coccinellids, which showed two developmental peaks: the first between June and July, and the second between September and October. Particularly the first peak showed large populations of coccinellid larvae in the weedy margins. Knowledge of the phenology of these beneficial predators assists in the design of management methods for ecological infrastructures to preserve and improve coccinellid and other predator populations.

Knowledge about the role of specific plants on the multiplication, life cycle and population dynamics of beneficial arthropods emerging from **chapters 2** and **3**, helps in selecting trees and shrub species within hedgerows, and to choose the key-weeds for restoration of degraded agroecosystems. Ecological and faunistic information on ECAs can also provide recommendations for the management of ECAs. Data of the present study were critically analysed also taking into account earlier studies conducted in northern Italy about coccinellid dynamics in ECAs and various crops (for references, see chapter 2 and 3). Figure 5 in **chapter 3,** which is presented here again (Figure 1), summarises the current hypothesis about the cyclic movement of coccinellids between arable crops, ecological compensation areas, fallow and open field vegetable crops in my study-area:

i) many plants within ECAs can supply multi-functional services to ladybirds, including multiplication sites and shelters. For example, the trees and shrubs *Prunus* spinosa, *Populus*, *Crataegus monogyna*, *Corylus avellana*, *Salix alba*, *Cornus sanguinea*, *Euonymus europaeus*, and the weeds *Cirsium*, *Rumex*, *Urtica dioica*, *Dipsacus and Crepis*, all supported the reproduction of ladybird populations;

ii) the period between late May and early July is crucial for the maintenance of predator populations because at that time many coccinellid species are in their reproductive period (**chapter 3**). In early summer coccinellid populations are migrating to and settling in weeds. These coccinellids originate mainly from the harvested alfalfa and wheat fields (Burgio et al., 1999, see references in chapter 2). **Chapters 2** and **3** demonstrate the role of field margins for recruiting and reproduction of these beneficials;

iii) in September-October, a second peak of coccinellid populations is registered on weeds, mainly represented by adults. Although I expect that in this period mowing might be less destructive for the beneficial fauna, weeds like *D. carota* and *A. retroflexus* (see **chapter 2**) still collect high populations of coccinellids that come from the last two alfalfa cuttings; in this period also shrubs and trees (i.e. *Prunus spinosa*, *Crataegus monogyna*, *Euonymus europaeus* and *Cornus sanguinea*) can play a role as shelter sites for coccinellids;

iv) besides coccinellids, also other beneficial predators including nabids, anthocorids, chrysopids and syrphids can reproduce on some trees and weeds (see **chapter 2** and **3**), confirming literature data of Sommaggio (1999, see references in chapter 7) and Boller et al. (2004, see references in chapter 1) and providing new phenological data for agroecosystems of northern Italy.

v) proper management of mowing, including timing, is recommended during the whole season in order to preserve and stimulate the development of insect predators, including coccinellid populations. Recommendations on the maintenance and management of ecological infrastructures have to be designed for a local scale considering the plant species within ECAs;

vi) management procedures for weedy borders should take into account the phenology of beneficial predators, but also potential negative effects such as the risk of weed infestation of the crop. Data presented in **chapter 2** and **3** can provide a guideline for management of ECAs. For example, the first cut of a weedy border should be made as late as possible and after the reproduction of the coccinellids, while using a procedure that is least harmful to the fauna (see e.g. Boller et al., 2004). In late summer and early autumn a weed like *Daucus carota* can supply shelter for coccinellids and should be preserved. Although *Cirsium* and *Rumex* have proved to be useful to encourage beneficial arthropods, care should be taken in management of ECAs to prevent these two species from becoming potentially troublesome weeds in cultivated areas.

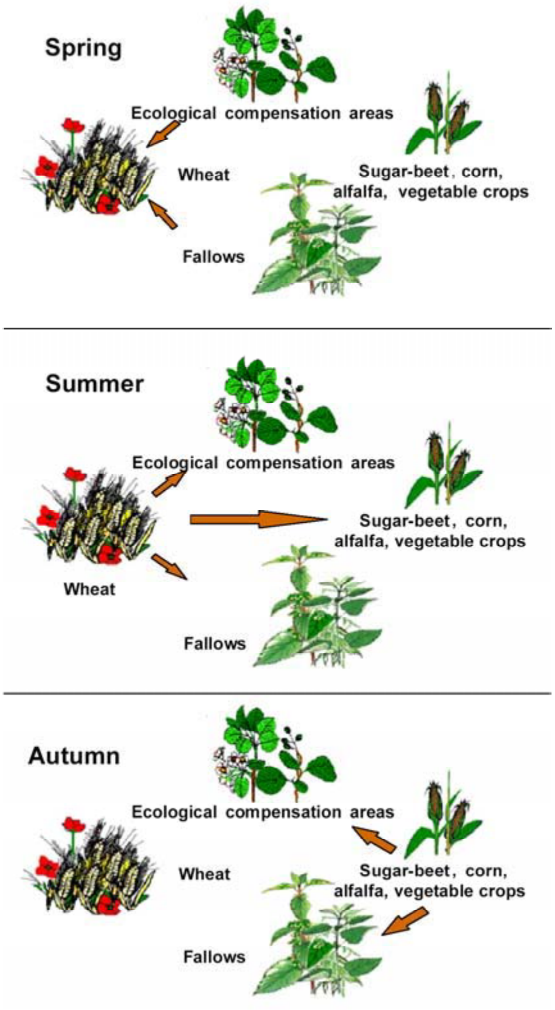

Figure 1. Diagram showing the cyclic colonisation of coccinellids between crops and non-crop areas

Function of farm scale ecological infrastructures for agromyzid parasitoids

In the second section, I present the results of a study of the system "ECAs-agromyzids–parasitoids". This study was done with the aim to improve conservation biological control of economic pests infesting crops in Emilia-Romagna. In **chapter 4** I demonstrate that weeds within ECAs show an enormous potential in the conservation of leafminers and their parasitoids: 24 agromyzid and 53 hymenopteran species emerged from a total of 25 weed species. Parasitoids were reared from agromyzids infesting the foliage of 34 weeds, but over 80% of the parasitic wasps were recovered from only 10 plant species. Creeping thistle was the most important source of parasitoids (26 different species), followed by weeds like *Plantago lanceolata* and *Sochus asper*. In my study several rare parasitoid species were collected, including six braconids, one eulophid and two pteromalids which are new records for the Italian fauna. The percentage of parasitism per site ranged from 40% to 70%, while the overall percentage of parasitism, calculated by pooling all data, was about 60%. Many agromyzid species seem to be closely related to a particular sampling site probably owing to a high density of their suitable host plants. On the other hand the parasitoids, which are in most cases very generalist species, seem to be affected by other factors, among others the total density of agromyzids on weeds. Parasitoid species composition showed a strong variation between years, probably in relation to climatic variation with resulting variation in weed and agromyzid population development.

In **chapter 5** I discuss a sampling method which is suitable for rapid decision-making in the case that *Liriomyza huidobrensis* infests lettuce. I demonstrate that binomial sampling and sequential sampling by the “stop lines” method are practical tools to monitor both the leafminer and parasitoid populations with an acceptable precision, even when the variability of parasitoid data was higher than that of the pest data. In **chapter 5** I also demonstrate that the mine stage was the most practical parameter to use for sampling *L. huidobrensis* populations on lettuce and this is a crucial conclusion for the development of an effective management strategy. This composite sampling method was easy and time-saving, because it took also the possibility into account to sample the larval parasitoid populations, which is needed for an estimate in the contribution of these beneficials to pest control. I found that the proportion of infested leaves was correlated with the mean number of larval endoparasitoids. The binomial sampling is useful to obtain information about the activity of parasitoids and gives a more complete image of the role of natural parasitism within the integrated management of *L. huidobrensis.*

In **chapter 6** I demonstrate that agromyzid parasitism on lettuce can be enhanced by creating a field edge consisting of a mixture of flowering plants. Field sampling and laboratory observations showed that flowering plants have a pronounced positive effect on parasitism by ectoparasitoids, though parasitism by endoparasitoids is generally higher than that of ectoparasitoids. The reasons for the differential effect of flowering plants on the stimulation of ecto- and endoparasitoid populations are still unknown and need to be investigated. Analysis of the field samples makes it possible to conclude that flowering field strips result in an improved synchronization between agromyzids and their parasitoids on lettuce, a crop characterised by a rapid production cycle. However this positive effect of synchronisation did not result in a significantly higher reduction of agromyzid damage in the crop but this might be the result of a low leafminer density in combination with a high level of natural parasitism in the control fields as well as in the fields with flowering plant border. Considering that flowering strips were studied in small plots and that no negative effects were registered, I suggest to repeat the field experiment in plots of larger dimensions and at higher pest density. By analysing the percentage of parasitism in lettuce plots without flowering strips, it can be concluded that natural parasitism in organic farms can be very high and sufficient to limit leafminer populations. This high level of natural parasitism could explain why since the year 2000 *L. huidobrensis* has become a secondary pest at organic farms and at IPM farms with a rational management of ECAs in Emilia-Romagna.

Functional biodiversity at the landscape scale

After presenting “farm-scale” cases of ecological infrastructures in the previous sections, I provide information about the role of insect functional biodiversity at the landscape scale in section 3. In **chapter 7** I use syrphids as landscape indicators for the rural environment of Emilia-Romagna. The syrphid fauna was sampled in nine rural sites characterized by different vegetation and landscape structures. My main objective was to see if I could detect differences in infrastructure conservation and quality of ECAs with the faunistic data. Also, I analysed the importance of the sampling methods. Malaise traps proved to be the most productive monitoring system, but showed to be less suitable to collect particular species. The syrphid fauna was partially influenced by the landscape complexity: the highest number of species was collected in the highest landscape complexity, confirming their role as landscape indicators. Besides this general trend, the landscape-complexity criterion was not totally reliable for characterization of syrphid diversity. The reasons may depend on the mobility of syrphids and on local effects due to the vegetation which could have resulted in discrepancies in the species assemblages. Several rare species were sampled, including *Ceriana conopsoides* and *Brachyopa scutellaris*. These species are usually recorded in deciduous forests (*Fagus* and *Quercus*) with mature, old trees and in deciduous forest with mature *Acer*, *Alnus* or *Fraxinus*, respectively. Speight (2004, see references in chapter 7) considers these syrphids as strong landscape indicators and, therefore, their presence in our rural landscape is interesting. In view of the fact that no deciduous forests are present in the study area, the larvae of these species may have emerged from old trees within the mature hedgerows present at the sites.

Ceriana, a very beautiful species which strongly resembles a wasp of the *Eumenes* group, was recorded in a site characterised by the highest complexity of landscape structure. On the other hand, *Brachyopa* was recorded within the lowest complexity of landscape structure and in a site characterised by grass and flower strips. This evidence confirms that the mobility of the adults of this group may create a "bias" in the data analysis concerning specific local appearance. Besides these considerations, recording of such rare bioindicator species seems to demonstrate the general good conservation function of the ECAs within the Emilia-Romagna landscape. In order to complete the faunistic analysis, I used an expert system called "Syrph the Net" which uses the biodiversity maintenance function (=BDMF, the ratio between observed and predicted species) to explore elements of site quality and site management. This information system, developed by Speight and Castella (2001, see references in chapter 7) and applied until now in Atlantic and Central Europe, proved to be an interesting tool to integrate classical environmental evaluations. The principle of Syrph the Net is simple: if the pool of species predicted to occur in a particular habitat is observed at a target site, then the biodiversity maintenance function is performing at maximum efficiency in that habitat at that site. To apply Syrph the Net it is necessary to know the regional pool of syrphid species. The first results obtained in the current study by Syrph the Net are promising. By means of Syrph the Net analysis, six of the nine sites sampled showed a good quality of the habitats *sensu* Speight et al. (2002, see references in chapter 7). One site in particular, within the highest landscape complexity, showed a value corresponding to top quality of environmental conditions. Information provided by Syrph the Net fits with the ecological analysis of the landscape and with the faunistic analysis of syphid fauna. Syrph the Net also seems suitable to distinguish the influence of the micro-habitat from that of the landscape on the syrphid communities. In order to be able to generalise the use of Syrph the Net, other field evaluations in various Italian rural landscapes are needed.

After an evaluation of the landscape quality by means of syrphid populations, I extended the study to other insect groups, such as carabids, butterflies and sawflies (chapter 8). I demonstrate that each insect group displayed different biodiversity patterns in relation to the different landscape/micro-habitat categories. In **chapter 8** a positive effect of the landscape structure and complexity was found for syrphids and carabids, while butterflies were more strongly affected by the micro-habitat characteristics. The species richness of syrphids and carabids also significantly increased from site scale, via the meso-scale to the landscape scale. Butterfly richness and abundances were significantly correlated with plant diversity and abundance, and inversely correlated with the structural architecture of the sites. I can confirm that the presence of specific micro-habitats, including plant species, is crucial for butterfly conservation. The position of sawflies is controversial and this group seems affected by both the vegetation types and the micro-habitat. Sawflies are poorly investigated in Italy, and further studies are needed in different rural contexts before they can be used as reliable indicators. As evinced from a recent investigation in Emilia-Romagna (Sommaggio, personal communication), species composition of this group seems to show a strong variability among years. For this reason the resulting biodiversity patterns vary a lot, which represents a crucial problem for environmental studies. The reason of this could also depend on the sampling method, but further studies are needed in order to clarify these aspects. Finally, sawflies and syrphid species richness were significantly correlated, but the reason is unknown because this correlation could also represent an artefact of the sampling system. Also in this case, more investigations are necessary.

I conclude from the information presented in **chapter 8** that it is crucial to select a suitable indicator for the specific scale of investigation within landscape management studies. Also, for a complete environmental analysis of the quality of the rural areas, a multidisciplinary approach is needed for optimal discrimination between the different solutions for conservation and biodiversity. In a functional biodiversity approach, it is important to study the conservation status of rare species and to provide suitable management interventions to save biota that are at extinction risk. The species lists I provide in **chapter 8** can be helpful in order to provide a data bank for agro-environmental analysis in Emilia-Romagna. Such data banks can also provide information about the changes in biodiversity patterns over time. Tools like Syrph the Net seem to be particularly suitable for giving a functional meaning to faunistic lists of insects in a landscape management approach. I strongly recommend such approaches in order to give practical and ecological relevance to biodiversity studies, and finally to use biodiversity patterns for conservation and implementation of management strategies for rural landscapes.

Epilogue

When I went to University in the early 1980s, monoculture was the major crop system practised in the Po valley of Italy, and non-crop plants were considered noxious elements in the rural landscape. Between 1980 and 1990, agriculture was involved in serious discussions about its future, because the paradigms of food production drastically changed. My own thinking and also the research represented in this thesis was influenced by these transformations. The chronological order of the research chapters reflect, in summary, the scenarios of agroecological studies in my country.

The first studies (chapter 2, 3 and 4) were characterised by a faunistic and rather general approach. In these years the first agro-environmental approaches were perceived as a “confrontation” by traditional farmers as well as by extension services. For this reason we started studies on ecological infrastructures with great caution, studying mainly basic aspects of insect conservation. Later, landscape management techniques and conservation biological control were accepted by most farmers. In this period, the creation of ecological compensation areas was considered in the IPM guidelines in Italy. Because of this, the interest in landscape management studies within a “crop context” increased (see chapter 5 and 6), and now, landscape management became an important part of the crop protection. More recently, the importance of spatial scale in ECA management became obvious in ecological entomology. Ecological studies demonstrated that diversity patterns within a habitat may depend on processes at a larger spatial scale than the habitat (see chapter 7 and 8). Also in practical applications like landscape management, a large-scale perspective was urgently needed for studying and using functional biodiversity.

The importance of scale in landscape ecology is, among others, expressed by the creation of the study group “Landscape Management for Functional Biodiversity” within IOBC (International Organization for Biological Control) (Rossing et al., 2003; 2006, see references in chapter 8). The activities in this working group influenced my most recent studies and they improved my insight in landscape and conservation biological control studies. The "large scale perspective" seems to show that new approaches in landscape studies are needed, involving for example the GIS-based experimental plans, the grid-monitoring based on referenced points and the statistical and descriptive analyses of the data at large spatial scale (i.e. geostatistics and spatial analysis by distance indices or SADIE). These methods deserve serious attention because they offer interesting approaches for studies concerning functional diversity, and they are certainly not only a fashion. Also, to be able to understand the role of landscape management in crop protection, more attention should be given to the dynamic patterns of arthropod pests at a large spatial scale in a multitrophic context. Although I have worked on this topic (Burgio et al., 2005, see references in chapter 8), it is not represented in my thesis.

Sadly, after the initial great interest of local and national governments in landscape management studies, limited research budgets make it very difficult to embark on further studies concerning functional biodiversity. Now that we have the first demonstrations in Italy and other countries that these studies can contribute to sustainable and environmentally cleaner production of crops, I hope that the interest in the role of ecological compensation areas for better agriculture and for conservation of biodiversity was not simply a passing fashion of farmers and politicians.

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Curriculum vitae of Giovanni Burgio

Giovanni Burgio was born in Bologna (Italy) on 27 January 1961. He graduated in Agricultural Science (University of Bologna) on 6 October 1987. After his graduation, he worked as consultant at Istituto di Entomologia "G. Grandi" (now DiSTA), University of Bologna, within a regional IPM project. In 1990 he attended with success the 15th Course of Statistical Methodology for basic and applied research, in Cortona (Italy) from 17 September to October 6, organized by the Italian Section of the Biometric Society.

Since 1999, Giovanni Burgio is appointed as Research Entomologist at the Department of Agroenvironmental Sciences and Technologies (DiSTA), of the Faculty of Agricultural Sciences, *Alma Mater Studiorum* University of Bologna.

He published about 110 scientific papers, including papers in journals with an impact factor, in the fields of biological control, IPM, monitoring and sampling of insects, agroecology, biology and ecology of beneficial insects, and molecular analysis of insects for biosystematics and diagnostics.

He is now teaching "General and Applied Entomology" and "Quantitative Ecology of Insect Populations" at the Faculty of Agricultural Sciences of Bologna, and "Biotechnology applied to arthropods" at the Faculty of Biotechnology of the Univeristy of Bologna.

His main topic of interest is conservation biological control, including landscape management and conservation of insect fauna. His particular expertise is the role and management of non-crop plants (ecological infrastructures) in rural landscape to enhance beneficial insect populations. Within this field, he is also studying advanced techniques like geostatistics for spatial data analysis of insects. His other topics of interest include: integrated pest management of insects, sampling techniques applied to insects, and insect systematics.

In 2003, he organized the first meeting IOBC/WPRS Working Group on "Landscape management for functional biodiversity" in Bologna and he is member of the scientific advisory board of this IOBC/WPRS Working Group.

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