Examensarbete

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Field margins vs. insecticides

-factors affecting the density of predators attacking *Plutella xylostella*

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Abstract

Biological control provides a tool to reach goals such as maintaining sustainable agroecosystems and decreasing the use of pesticides. Studies show that generalist predators can reduce prey populations effectively and, thus, may function as good biocontrol agents. Unfortunately, generalist predators have been exploited to a small extent in biological control and little is known about how different factors can affect their density.

The diamond back moth, *Plutella xylostella,* is a major insect pest on cabbage throughout the world but still few studies have been conducted on possible predators and factors that affect their density. Therefore, this study focuses on (1) identifying predators of *P. xylostella* and (2) investigating how insecticide use and type of field margin affect the density of predators in cabbage fields. The study took place in Nicaragua in six different cabbage fields, three conventional and three semi-organic. Three methods were used to measure the density of predators weekly during six weeks; d-vac, pit-fall traps and observations. According to the results more predators were found in the field margins than in the cabbage fields. The factor that affected the density most was the type of field margin surrounding the field. Field margins with a high proportion of natural vegetation had a higher number of predators compared to prepared or newly sowed margins. The amount of insecticides used affected predator density negatively only when used very frequently. Among the three major predator groups found (Araneae, Coleoptera and Hemiptera), Hemiptera was the only one which showed any difference between the two different farm types; on semi-organic farms there was an increase in density at the end of the observation period whereas the density tended to decrease on conventional farms as shown by a significant farm type by time interaction. The results also showed that high numbers of *P. xylostella* were never observed when there were a high number of predators.

In conclusion, my results suggest that field margins may function as refuges for arthropod predators and that these refuges can have a bigger impact on the number of predators than the amount of insecticides used. The practical implications of these results are discussed and to my knowledge, there are no similar results reported previously in the literature from this or similar systems.

Table of contents

Introduction

Farmers all over the world have started to realise that the economic losses from pesticide applications on a crop can be bigger than the loss caused by pests in untreated fields and an overuse of pesticides can lead to an insecticide resistance (Symondson et al. 2002). To decrease the use of chemical pesticides and to have a sustainable agroecosystem, biological control is an excellent alternative. During recent years research has shown that generalist predators are good biocontrol agents and can effectively reduce prey populations (Snyder and Wise 1999; Symondson et al. 2002). Generalist predators can decrease the density of pests without a decline in their own numbers and, thus, prevent a re-invasion of the pest. This is because generalist predators can survive on other prey than the specific pest whereas specialist predators may go extinct. Diverse groups of generalist predators can often be found in relatively high numbers in field margins but few studies have been performed to analyse if this can have any effect on the biological control within the field (Symondson et al. 2002). Furthermore, few studies have been performed on how the cultural practices, such as the amount of natural vegetation left in field margins, can increase the effectiveness of natural enemies (Schellhorn and Silberbauer 2002). By increasing the vegetation diversity in the field margins the number of natural enemies can increase in the field (Tsitsilas et al. 2006, Schellhorn and Sork 1997). For example, in one study more spider and coleoptera individuals were found in organic than conventional fields but it is unclear if the landscape affected the results (Schmidt et al. 2005).

The diamond back moth, *Plutella xylostella* (L) (Lepidoptera: Plutellidae), is a major pest throughout the world, and the larvae damage crucifers, especially Brassica crops such as cabbage, broccoli, and cauliflower. The larvae destroy the cabbage head which gives large economical losses. When synthetic insecticides were introduced and used to a large extent during the 1950's, *P. xylostella* developed a resistance to insecticides. In addition, it was the first insect which developed resistance to the bacterial insecticide *Bacillus thuringiensis* (Talekar and Shelton, 1993). In Central America cabbage is an important crop and it is cultivated all year around. Therefore, *P. xylostella* can have a continuous development cycle and cause huge damage in cabbage cultivations (Andrews et al, 1991). One way to control *P. xylostella* and at the same time decrease the use of insecticides is to apply biological control. Studies show that the parasitoid *Diadegma semiclausus* (Hymenoptera: Ichneuminidae) have been successful in controlling *P. xylostella* populations in Southeast Asia (Talekar and Shelton, 1993).

Little is known about generalist predators and how different factors can affect their density (New 2007). Due to the successful methods utilising with parasitoids, relatively few studies have been made on potential predators as natural enemies to *P. xylostella* (Furlong, 2004a). The few studies made often only contains a list of species and nothing is mentioned about their eating capacity, the density or possible factors that can affect the density (Guan-Soon,1991). As mentioned above, one disadvantage with parasitoids is that they often are more specialized than predators, which may result in less stable biological control over time.

The aim of this project was to quantify the density of potential predators of *P. xylostella* in cabbage fields, both semi-organic and conventional. The aim was also to evaluate the relative importance of the two factors (1) vegetation in the field margins and (2) usage of insecticides on the density of predators of *P. xylostella*.

Material & Methods

Description of study site

The field study took place between October 13th and November 22nd 2006 in Nicaragua and was done in collaboration with Freddy Miranda, Universidad Nacional Agraria (UNA), who is running a PhD project, about different ways to control *P. xylostella* in a biological way. The field work was done together with Linda Larsson, agronomy student at Swedish Agricultural University (SLU). Our study includes six of Miranda's twelve fields, situated on different farms (Lat. 12 59´ N; Long. 086º 22´W) in the natural reserve Tisey Estanzuela close to Estelí on an altitude of 1500 meters above sea level These six fields were selected because cabbage was planted around the same time, 19 September to 27 September, on all farms. Three of our fields were semi-organic and the other three were conventional. The fields vary with respect to their previous use, including insecticide use; see below for a more detailed description. See also under the sub-heading "Insecticide use" below for a description of differences between the two farm types. Due to the landscape being hilly with fields situated in inaccessible places, most of the fields are prepared by oxen or by hand. Few fields are prepared by tractor. The size of the fields varied between 0.07 ha to 0.11 ha, with an average of 0.09 ha. The seedlings were brought up in a small nursery for one month before planting. The seedlings for the conventional farms were planted close to the field whereas the seedlings for the semi-organic were brought up in a green house.

Description of the field. Field numbers 1, 2 and 6 have earlier been in fallow. Potatoes were the previous crop on fields 3, 4 and 5. The average plant density of the current cabbage in the fields were 4.4 plants/m^2. Fertiliser (NPK 12-30-10) was applied at sowing at all fields. Fifteen days after the planting home-made bionutrients were applied to field number 1 and ammonium (Multifet) to field number 6. Field number 6 were also treated with Agrimicel and Urea after two weeks. After 30 days field number 3, 4 had NPK (15-15-15) applied. Field number 6 received ammoniumsulfat (Solufeed) three times during the cultivation period, and field number 5 urea after 35 days.

Field methods

The fields were visited six times, with six to seven days between each visit. Four different methods were used in each field to measure the density of potential predators; observation, net-sweeping, vacuum insect net (i.e. d-vac:ing) and pit-fall traps. The observations were done on ten plants, at six different places within the field. Each plant was observed between 10 to 20 seconds depending on cabbage size and all arthropods noted. Four places were selected in the field for the net-sweeping. The sweep net had a diameter of 27 cm. Each place was ten meters long and the sweeping was done over four rows of cabbage. D-vac:ing was used on six different places in the field and one in each field margin (normally four in each field). A square of 1.5 x 1.5 m was d-vaced for 27 seconds on full effect to produce one sample. During the second week of the study pit-fall traps were used. Every field had five pit-fall traps, two in the middle of the field (a minimum of six meters from the field margin) and the rest in the third row from different field margins. The traps were made of plastic and were buried in the soil, with the rim level with the soil surface. After two weeks the traps were moved to other places in the field but with the same pattern. All plots and places used in and around the field with the different methods were randomly selected. The observations and net-sweeping did not yield substantial information and their results will not be presented here.

Although the pit falls caught a large number of arthropods, pit-fall trapping might not be the best method for sampling the arthropod predators of *P. xylostella* (Furlong, 2004b). I will, therefore, concentrate on the d-vac method. There was no significant correlation between d-vac sampling and pit-fall traps ($p>0.05$). Every week the height of the cabbage at each field were measured.

Field margins

The height of the vegetation in the field margins was measured at the place were the d:vacing was done every week and photographs were taken at every sampling site. The arthropods in the plastic bags from the d-vac:ing were identified the same day as the sampling or the day after. All the potential predators were identified and some of them tested in a further feeding rate study conducted in the laboratory (reported in Linda Larsson's master thesis, 2007) to find the predators of *P. xylostella* and to investigate feeding capacity.

Different field margins and their species. The field margins surrounding the fields in the study can be divided into different groups according to what kind of vegetation it contained. The most common weed species were identified by Mario Cerna at UNA. The field margins with natural vegetation contained mainly the species presented in Table 1. Other types of field margins included pasture, another cultivated field, a prepared and newly sowed field, mowed grass/track and fence.

Table 1. Dominant plant species in the field margins surrounding the cabbage fields in Nicaragua.

Examples of species	Family
Oplismenus burmanii	Poaceae
Commelina sp	Commelinaceae
Amaranthus viridis	Amaranthaceae
Sida rhombifolia	Malvaceae
Nicandra physalodes	Solanaceae
Portulaca oleracea	Portulacaceae
Bidens pilosa	Asteraceae
Ageratum conyzoides	Asteraceae

Insecticide use

Initially it was thought that three of the fields were semi-organic and three of the fields conventional. Semi-organic farms mean that they use fertilizers, but not insecticides, whereas on the conventional fields both fertilizers and insecticides are used. In this study the division between the two types was difficult because of the variation among farms within groups. Some of the semi-organic fields had, before the project started, been treated as conventional whereas others have been semi-organic as long as they have been cultivated. To make the practice at each field more clear the farmers and sometimes their workers were interviewed and asked about the amount of insecticides used and the time of spraying, see Table 2. The fields are ranked based on how much insecticides are used. Farm number 1 used least insecticides and farm 6 most.

Limitations of the field methods

In some of the field margins the vegetation made it difficult to take proper samples. We had to take into account that we might have affected the results from the collecting of predators with d-vac though we walked in the field and made observations before the d-vac:ing. On the other hand the disturbance should more or less have been the same on all the fields. The weeding could also have had some affect on the number of predators since the collection sometimes took place directly after a weeding. The application of insecticides could also affect the number of predators. The identification was done by hand in the laboratory and it is possible that we could have failed to recognise some species as potential predators.

Statistical analyses

The density of predators in field margins and fields were compared using a paired t-test with each field as an independent observation. The relationship between the number of predators in the field margins and in the fields was analysed in a correlation analysis with the weekly observations from individual farms as observations with the aid of Minitab version 14. Repeated measurements ANOVA (Proc Mixed, SAS version 9.1) were used to investigate the difference in predator density between the two farm types, semi-organic and conventional, and how densities varied over time. Predator types were analysed separately with appropriate covariance structure selected for each data set. The results collected in the field and in the field margins were tested individually. Araneae, Coleoptera and Hemiptera were the three major groups of potential predators tested.

Field margins. To determine if the different margin types affect the density of predators in the field, the different field margin types were classified to obtain a potential predator pool index.

Farm index = (% of refuge type x) × (mean of predators/refuge type x/field)

Linear regression (Minitab version 14) was used to evaluate the relationship between the potential predator pool index and the sum of predators collected in each field.

Insecticide use. The fields were ranked based upon the use of insecticides (see Table 2) to be able to evaluate the effects of intensity of insecticide use. Difficult to get consistent results from the interviews. We have made an estimate of how much they have used. From the different interviews we can allocate the insecticide rank for each field. The more insecticides used, the higher the rank.

Table 2. The results from the interviews made with the farmers and their workers of the conventional fields. No interview was made with the worker at farm 5 and farmer at farm 6. The interviews were made by us (Lina Grönberg and Linda Larsson) and by Freddy Mirandas field assistant.

Insecticides and number of applications			
farm	farmer	worker	assistant
4	Avaunt x 2	Dipel x 1	Dipel x 3
5	Spintor x 4	-	Spintor x 1
	Avaunt x 1	-	Avaunt x 1
	-	-	Endosulfan x 1
	-	-	Monarca x 1
6	-	Thimet x 1	MTD x 4
	-	Avaunt x 2	Deltamethrin x 4
	-	Dipel x 3	Dipel x 3
	-	Proaxis x 2	-

The different farms were compared too see if there was any connection between the total amount of predators on each farm and insecticide use.

Results

All the predators that were found during the six weeks the study was carried out are listed in Appendix 1. The overall number of predators collected in the field on each farm varied between 20 and 157. The total number predators collected in the field margins on each farm varied between 97 and 308.

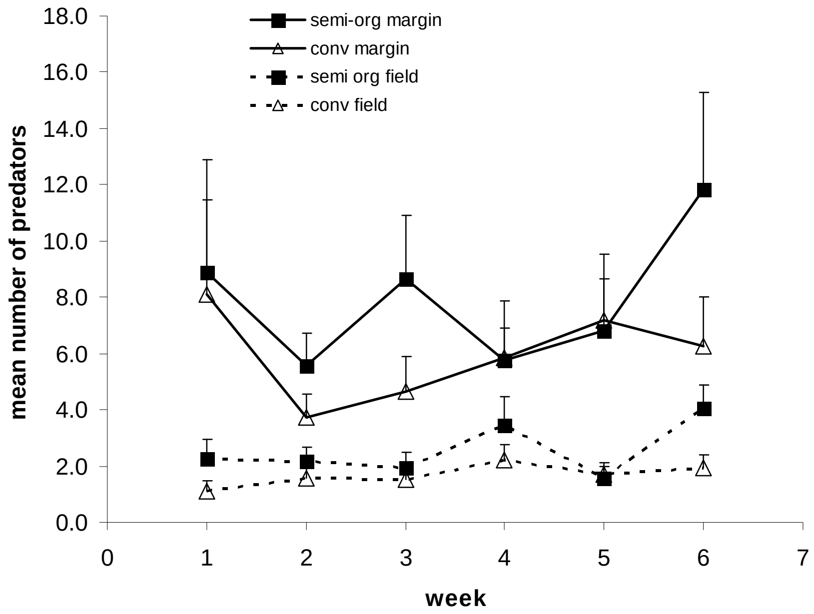

Fig. 1. The mean number of arthropod predators (+ SE) sampled in the field margins and the fields of semi-organic- and conventional cabbage fields (in Nicaragua) sampled over a six week period N(field)=6, N(field margin)=4.

The mean number of predators in the field margin was 53 % higher than in the field (paired t-test, $t = 5.73$, $p= 0.002$, $df = 5$) see figure 2. The results shows that there is a difference between the number of predators collected in the field compared to the ones collected in the field margins. As shown in figure 1, there are on average more predators collected in the field margins than in the field.

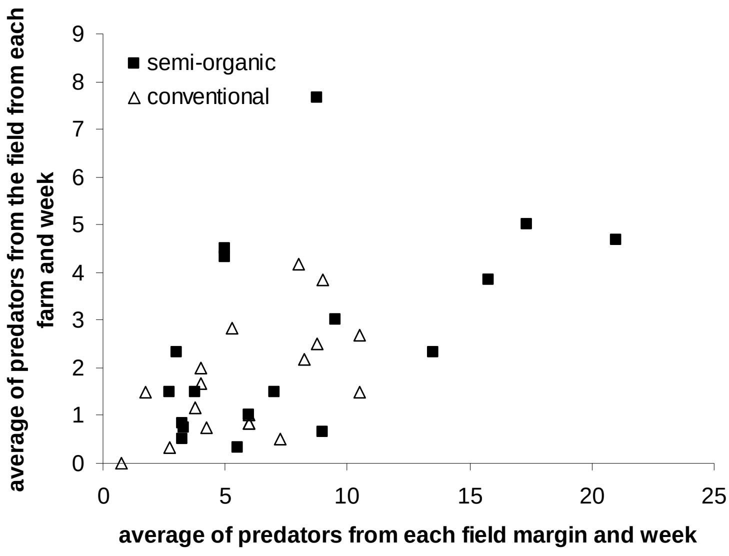

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Fig. 2. Relationship between the mean numbers of arthropod predators sampled in the field margins and in the fields of semi-organic and conventional fields sampled weekly in cabbage cultivations in Nicaragua.

There was a positive correlation between the predators in the field and the predators in the field margins (r = 0,552, p = 0.000, N = 30). A high number of predators in the field is related to a high number of predators in the field margin.

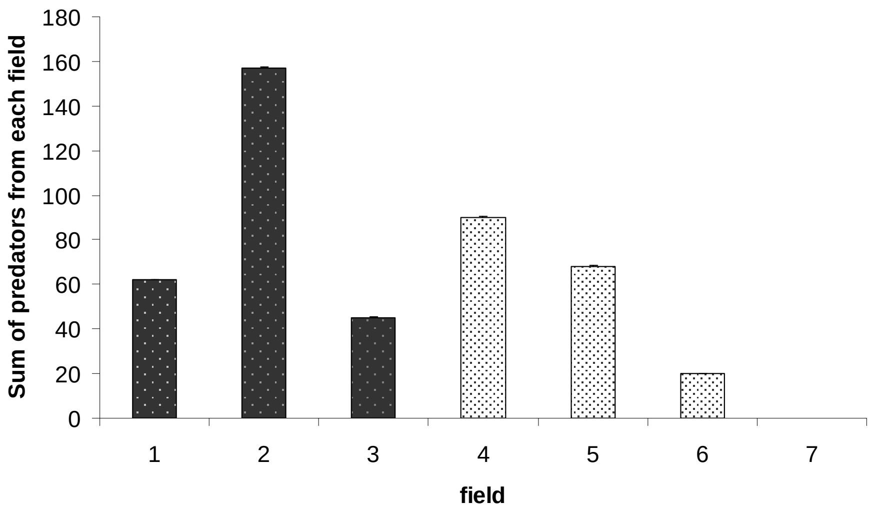

Fig 3. The total number of arthropod predators sampled with a d-vac from semi-organic and conventional fields in Nicaragua over a six week period, N=6. The dark bars are semi-organic farms and the pale bars conventional farms.

The results from the repeated measurement ANOVA of the total number of predators showed that there were no significant effect (p>0.1) of farm type or time in fields or field margins. Farm number 2 has the highest number of predators during the whole period and has a high peak in week 4. The number of predators increases the last week on all farms except on farm number 3.

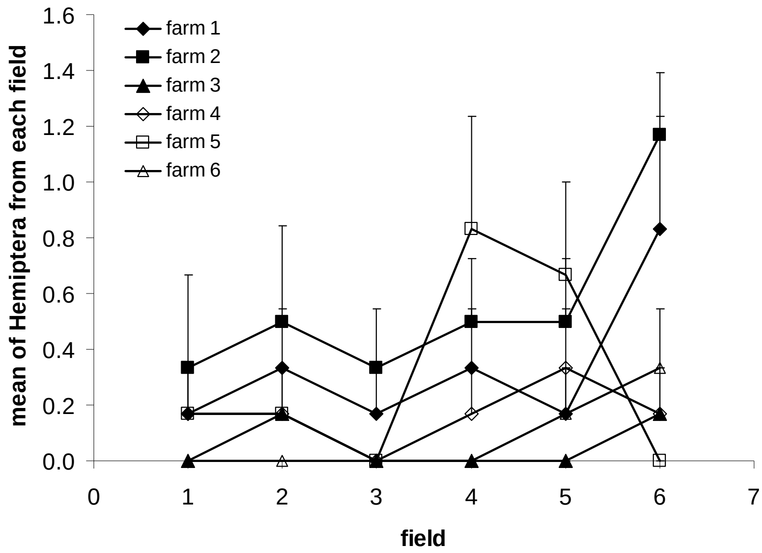

Fig. 4. The mean number of Hemiptera (+ SE) sampled from semi-organic and conventional fields in Nicaragua over a six week period.

The analyses of separate predator groups, Araneae and Coleoptera revealed no significant effects in either data collected in the field or the field margins. The interaction between time and farm type was however significant for the Hemiptera group in the field (Fig. 4; p=0.046) but not in the field margins. The significance implies that it was a difference between the farm types in Hemiptera density and that it also was a variation over time.

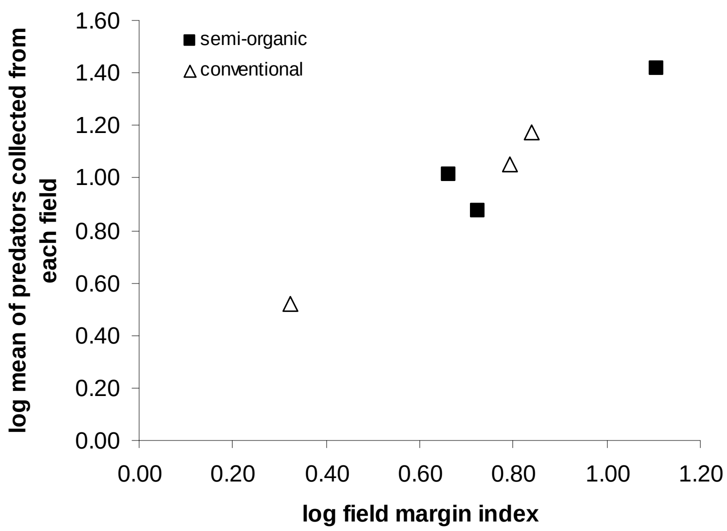

Fig. 5. The logarithmic mean of arthropod predators sampled from semi-organic and conventional fields in Nicaragua over a six week period vs. the logarithmic field margin index for the same fields.

More predators were caught with the d-vac in fields with a high field margin index (Fig. 5; r^2 (adj) = 0.95, p = 0.001, df =5) according to the regression analyses. One of the semi-organic farms has the highest rank and number of predators whereas one of the conventional has the lowest both in rank and number of predators.

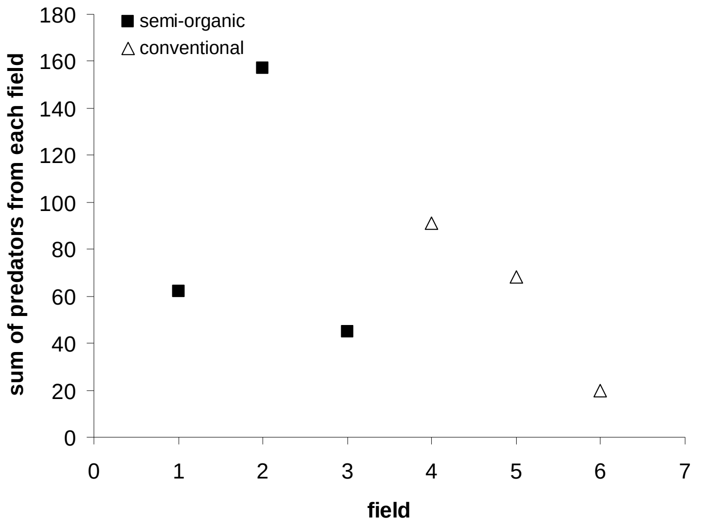

Fig. 6. The sum of the arthropod predators sampled from semi-organic and conventional fields in Nicaragua vs. the insecticide rank for the same fields.

Figure 6 gives an indication that there was a negative association between the sums of predators collected in the fields vs. insecticide use rank on conventional farms. The semi-organic farms have a less clear association than the conventional.

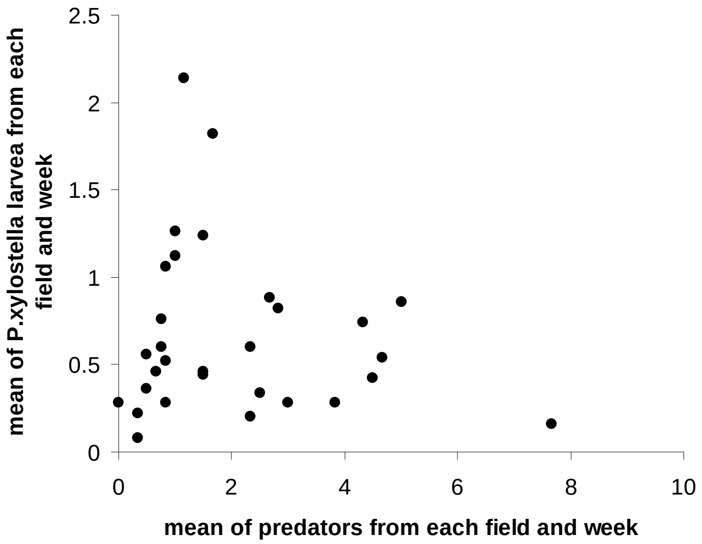

Fig. 7. The mean number of arthropod predators sampled from semi-organic and conventional fields in Nicaragua over a six week period vs. the average number of *P. xylostella* larvae sampled from the same semi-organic and conventional fields over a six week period.

The results from the correlation between the means of predators vs. the mean of *P. xylostella* larvae showed no significance ($r = -0.138$, $P = 0.468$, $N = 27$). It is worth noting that a high number of *P. xylostella* larvae never were found when there were a high number of predators. The lack of observations in the upper right corner in the figure indicates that if there are a high number of predators there is not a high number of *P. xylostella*.

Discussion

According to the results more predators were found in the field margins compared to in the fields (Fig.1) and more predators were found in the fields surrounded by margins with a lot of natural vegetation (Fig.5). The conventional farms which used more insecticides had the lowest number of predators (Fig.1).

The factor that appears to increase the predator density in the field the most was the type of field margin which surrounded the field in question. More specifically, a high density of natural vegetation had a positive effect on the density of predators. Therefore, it indicates that the field margins functioned as refuges for the predators. The fact that the density of predators was always higher in the field margins than in the field (Fig.1) strengthens this conclusion. The predators probably emigrated from the refuges into the field to search for prey. This is a well-known phenomenon, observed in many systems (Burgio et al. 2006). Weedy field margins give a high biodiversity and can support a high and relatively stable density of predators. The movement between field and field margin is important for sustainable agriculture (Burgio et al. 2006) but the factors affecting these movements are in most cases poorly understood (Schellhorn and Silberbauer, 2002). For example, the availability of prey in the field margins may affect the propensity of a predator to leave a field margin.

The ranking of the field margins with respect to “quality” for predators is also a measure of how much natural vegetation the field margin contains which suggests that fields with a lot of natural vegetation have a high density of predators. Refuges may contribute to the stability of predator-prey interactions (Berryman and Hawkins 2006) and minimise the disturbance on the field which can increase the density and recolonisation of natural enemies (Schellhorn and Silberbauer 2002). The change in density of predators over time was not significant, indicating that the fauna is stable due to the refuges. Thus, it appears that the refuges can minimise the impact of insecticide applications in the field on predator populations and keep them stable.

The results in this study suggest that the refuges can have a bigger impact on the number of predators than the amount insecticides used if chemical insecticides are not frequently used, since this clearly reduce the number of predators. One previous study has shown that fields which are heavily sprayed have an extremely low spider density (Nyffeler and Sunderland, 2002) which is also the case in our study (Fig. 3). However, only Hemiptera showed any difference between semi-organic and conventional farms among the three major groups of predators found (Fig. 2). It is difficult to draw any conclusions concerning the sensitiveness to insecticides for Hemiptera since so few individuals were collected. The farm which used most insecticides had also the highest amount of *P. xylostella* and the lowest amount of predators. The field from the earlier period had a high density of *P. xylostella* and was situated close to the field in the later study and it is possible that *P. xylostella* immigrated there. The frequent use of insecticides probably killed many predators whereas a fraction of *P. xylostella* may have been resistant to the insecticides used (cf. e.g. Talekar and Shelton1993). Studies show that insecticides applied frequently almost totally suppresses beneficial arthropod populations (Riechert 1984).

However, there can be other factors which affect the density of predators in the field. The previous use and treatment of the field can for example have an affect. One study says that less disturbance in the field will contribute to more natural enemies (Schellhorn and Silberbauer 2002). The clearing of weeds, the application of insecticides and fertilizers, and also the collection of insects with the d-vac can be seen as disturbances which reduce the number of predators. Straw mulches in the field can also contribute to a higher density of predators (Symondson et al. 2002). The establishment rate of natural enemies can be decreased in monocultural systems since they have intense and frequent disturbances (Landis et al. 2000). Some of the semi-organic fields in this study had earlier been conventional and vice versa which also can be a factor which gives different densities of predators in the fields. All the factors which affect the density of predators also affect the density of *P. xylostella.*

According to our data and results from other fields in the same area (Freddy Miranda personal communication) there never seems to be high abundance of *P. xylostella* and predators at the same time. These results, i.e. no observations in the upper right corner in Fig. 7, indicate that the predators have a negative impact on *P. xylostella*. However, low densities of *P. xylostella* may also occur when predators occur in low abundance. The reason behind observations of this type is unknown. Whether this is a general pattern, which can be observed also in other parts of the world, or not, remains to be shown.

An important factor for successful biological control that needs to be improved is the connection between the researchers and the farmers. One thing which might make the communication better is to start and develop more IPM (Integrated Pest Management) programmes where the farmers can participate in research programmes and increase the knowledge of biological control. Predators of insect pests often constitute a complex of species and more research needs to be done with predators in order to increase the use of biological control and keep a sustainable agroecosystem with a decrease in the use of insecticides. Well designed research programs, involving farmers, may provide data that can be used to increase our knowledge about these complex interactions.

In conclusion, my results suggest that field margins may function as refuges for arthropod predators and that these refuges can have a bigger impact on the number of predators than the amount of insecticides used. This conclusion is based on that there are always more predators in the field margin than in the field and fields with a high density of predators in the field also have a high rank in field margin. There seems to be no earlier studies made on the connection between field margins and insecticide use. Therefore, the results in this study can be seen as unique but further studies need to be done to investigate this more since the observations in this study were relatively few. It would also be of great interest to see if this phenomenon can be documented in other systems. One way to improve in further studies is to coordinate the use of insecticides since this can affect the density of predators. It would be interesting to know how much insecticides that needs to be used to make that factor more important than the type of field margin surrounding the field.

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Refererences

Andrews KL, Sanchéz RJ, Cave RD, 1991, *Management of Diamond Back Moth in Central America*, Management; proceedings of the second International workshop

Berryman AA, Hawkins BA, 2006, *The refuge as an integrating concept in ecology and evolution,* Oikos, 115:1

Bugio G, Ferrari R, Boriani L, Pozzati M, van Lenteren J, 2006, *The role of ecological infrastructures on Coccoinellidae (Coleoptera) and other predators in weedy field margins within northern Italy agroecosystems,* Bulletin of Insectology 59(1): 59-67

Furlong MJ, Zu-Hua S, Yin-Quan L, Shi-Jian G, Yao-Bim L, Shu-Sheng L, Zalucki, MP, 2004a, *Experimental analysis of the influence of pest management practice on the efficacy of an endemic arthropod natural enemy complex of the diamond back moth*, Journal of economic entomology 97 (6): 1814-1827

Furlong MJ, Shi Z-H, Liu S-S, Zalucki P, 2004b, *Evaluation of the impact of natural enemies on Plutella xylostella L.(Lepidoptera: Yponomeutidae) populations on commercial Brassica farms,* Agricultural and Forest Entomology, 6:311-322

Guan-Soon L, 1991, *Integrated management of DiamondBack Moth: Practical realities?* Management; proceedings of the second International workshop

Landis DA, Wratten SD, Gurr GM, 2000, *Habitat management to conserve natural enemies of arthropod pests in agriculture*, Annu. Rev. Entomol. 45:175-201

Larsson L, 2007, *Predators of Plutella xylostella in Nicaragua. Feeding capacity and potential role in biological control*, Master thesis in biology, Swedish Agricultural University, SLU

New TR, 2007, *Are predatory arthropods useful indicators in Australian agroecosystems?,* Australian Journal of Experimental Agriculture, 47: 450-454

Nyffeler M, Sunderland KD, 2002, *Composition, abundance and pest control potential of spider communities in agroecosystems: a comparison of European and US studies,* Agriculture, Ecosystems and Environment, 95:579-612

Riechert SE, Lockley T, 1984, *Spiders as biological control agents,* Ann. Rev Entomol. 29:299-320

Schellhorn NA, Silberbauer L, *The role of surrounding vegetation and refuges: increasing the effectiveness of predators and parasitoids in cotton and broccoli*, First International Symposium on Biological Control of Arthropods

Schellhorn NA, Sork VL, 1997, *The impact of weed diversity on insectpopulation dynamics and crop yield in collards, Brassica oleracea (Brassicaceae),* Oecologia, 111:233-240

Schmidt MH, Roschewitz I, Thies C, Tscharntke T, 2005, *Differential effect of landscape and management on diversity and density of ground-dwelling farmland spiders,* Journal of Applied Ecology 42: 281-287

Snyder WE, Wise DH, 1999, *Predator interference and the establishment of generalist predator populations for biocontrol,* University of Kentucky, Department of Entomology, Biological control 15: 283-292

Symondson WOC, Sunderland KD, Greenstone MH, 2002, *Can generalist predators be effective biocontrol agents?,* Annu. Rev. Entomol. 47:561-94

Talekar NS, Shelton AM, 1993, *Biology, ecology and management of the diamond back moth,* Annu. Rev. Entomol 38:275-301

Tsitilas A, Stuckey S, Hoffmann AA, Weeks AR, Thomson LJ, 2006, *Shelterbelts in agricultural landscapes suppress invertebrate pests,* Australian Journal of Experimental Agriculture 46:1379-1388

Appendix 1

Predators found in fields and field margins and the number of different groups in each family

Order	Family	Genera	Number of separated groups in the family
Araneae	Araneae		2
Araneae	Araneidae		3
Araneae	Gnaphosidae		1
Araneae	Linyphiidae		3
Araneae	Lycosidae		12
Araneae	Salticidae		14
Araneae	Tetragnathidae		2
Araneae	Thomisiidae		17
Coleoptera	Staphylinidae l.		1
Coleoptera	Staphylinidae	Paederus	1
Coleoptera	Staphylinidae	Tachinus	1
Coleoptera	Staphylinidae		7
Coleoptera	Carabiae		1
Dermaptera	Forficulidae	Dorus	1
Diptera	Syrphidae	Baehar	3
Hemiptera	Coreidae		1
Hemiptera	Gelastonicoridae	Gelastocoris	1
Hemiptera	Miridae	Lygus	1
Hemiptera	Nabidae	Nabis	14
Hemiptera	Pentatomidae/Miridae l.		1
Hemiptera	Reduviidae	Sinea	1
Hymenoptera	Vespidae	Polybia	2
Opiliones			5

Appendix 2

Predators found in the fields and field margins with the different methods in the semi-organic fields.

			Farm 1				Farm 2				Farm 3			
Order	**Family**	**Genera**	**obs.**	**pit-fall**	**field**	**field margin**	**obs.**	**pit-fall**	**field**	**field margin**	**obs.**	**pit-fall**	**field**	**field margin**
Araneae	Araneae		2	100	8	3	3	58	28	30	3	11	7	17
Araneae	Araneidae		1	0	0	0	0	0	0	0	0	0	0	1
Araneae	Gnaphosidae		0	1	0	1	0	0	1	0	1	0	0	0
Araneae	Linyphiidae		3	0	1	0	1	0	0	0	0	0	0	0
Araneae	Lycosidae		1	128	24	15	16	200	45	38	0	17	1	1
Araneae	Salticidae		0	0	2	10	2	0	4	21	0	0	5	33
Araneae	Tetragnathidae		7	0	2	4	12	2	12	15	5	3	4	11
Araneae	Thomisiidae		0	0	0	8	0	0	3	13	0	0	0	21
Coleoptera	Staphylinidae l.		0	1	0	4	0	1	4	17	0	0	7	4
Coleoptera	Staphylinidae	Paederus	0	2	0	2	0	1	4	17	0	0	7	4
Coleoptera	Staphylinidae	Tachinus	0	0	1	8	0	0	3	4	0	0	0	0
Coleoptera	Staphylinidae		0	109	2	1	1	28	26	28	1	14	17	18
Coleoptera	Carabiae		0	0	0	0	0	14	2	5	0	0	0	1
Dermaptera	Forficulidae	Dorus	0	0	0	1	0	0	0	0	0	0	0	3
Diptera	Syrphidae	Baehar	1	1	0	4	3	0	2	3	2	0	0	0
Hemiptera	Coreidae		0	0	0	0	0	0	0	1	0	0	0	1
Hemiptera	Gelastonicoridae	Gelastocoris	0	0	0	0	0	3	0	0	0	3	0	1
Hemiptera	Miridae	Lygus	4	0	4	12	1	0	3	8	0	0	0	0
Hemiptera	Nabidae	Nabis	0	0	7	15	1	0	12	56	0	0	2	4
Hemiptera	Pentatomidae/Miridae l.		0	0	1	4	0	0	5	50	0	0	0	2
Hemiptera	Reduviidae	Sinea	0	0	0	0	0	0	0	1	0	0	0	0
Hymenoptera	Vespidae	Polybia	1	1	0	0	1	2	0	1	2	0	0	0
Opiliones			0	52	1	7	3	45	8	9	0	0	2	2

Predators found in the fields and field margins with the different methods in the conventional fields.

			Farm 4				Farm 5				Farm 6			
Order	Family	Genera	obs.	pit-fall	field	field margin	obs.	pit-fall	field	field margin	obs.	pit-fall	field	field margin
Araneae	Araneae		7	13	5	7	2	44	6	9	0	5	3	8
Araneae	Araneidae		0	0	0	2	0	0	0	0	0	0	0	0
Araneae	Gnaphosidae		2	0	1	1	0	0	2	4	0	0	1	0
Araneae	Linyphiidae		7	0	1	0	4	0	0	2	3	0	3	2
Araneae	Lycosidae		7	183	11	10	4	78	8	17	0	27	1	4
Araneae	Salticidae		10	0	14	12	6	1	6	18	3	0	3	8
Araneae	Tetragnathidae		27	0	4	8	15	0	6	21	1	0	1	1
Araneae	Thomisiidae		3	0	13	41	1	0	7	28	1	0	0	2
Coleoptera	Staphylinidae l.		0	0	9	25	0	4	1	7	0	0	1	2
Coleoptera	Staphylinidae	Paederus	0	0	9	25	0	4	1	7	0	0	1	2
Coleoptera	Staphylinidae	Tachinus	0	0	0	4	0	0	0	2	0	1	0	0
Coleoptera	Staphylinidae		17	20	22	20	3	150	18	19	1	90	4	22
Coleoptera	Carabiae		0	0	0	0	0	2	0	0	0	23	0	0
Dermaptera	Forficulidae	Dorus	0	0	0	1	0	0	0	6	0	0	0	0
Diptera	Syrphidae	Baehar	0	0	0	1	1	0	0	1	0	0	0	2
Hemiptera	Coreidae		0	0	0	0	0	0	0	0	0	0	0	0
Hemiptera	Gelastonicoridae	Gelastocoris	0	1	1	0	0	1	0	0	0	0	0	0
Hemiptera	Miridae	Lygus	2	0	2	3	0	0	2	1	0	0	3	4
Hemiptera	Nabidae	Nabis	2	0	1	9	0	1	8	2	0	1	0	20
Hemiptera	Pentatomidae/Miridae l.		0	0	0	29	0	0	1	12	0	0	0	15
Hemiptera	Reduviidae	Sinea	0	0	0	0	0	0	0	0	0	0	0	1
Hymenoptera	Vespidae	Polybia	2	0	1	1	0	2	0	1	0	0	0	1
Opiliones			4	53	6	4	1	1	0	0	0	0	0	0