

Enhanced pest control in cabbage crops near forest in The Netherlands

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Abstract Landscapes are composed of a multitude of habitat types which, potentially, can influence natural enemy populations. The contribution of specific habitat types to sustaining natural enemy populations in agricultural landscapes and the associated ecosystem service of pest control is not well understood. We investigated how landscape composition affected parasitism rates in 22 organic Brussels sprout fields in The Netherlands. Second and third instar larvae of *Plutella xylostella* were placed on experimental Brussels sprout plants in Brussels sprout fields and were recovered after two days in the field. Parasitism rates ranged between 4 and 94% and were related to landscape variables at a scale of 0.3, 1, 2 and 10 km. Univariate analysis using a generalized linear mixed model indicated that parasitism rates were positively related with area of forests at a scale of 1, 2 and 10 km, forest edges at a scale of 1 and 2 km and road verges at a scale of 1 km. Forest and road verges are likely to provide

food and alternative hosts for parasitoids and are less disturbed habitats than agricultural fields. These results suggest that forests and road verges may play an important role in sustaining effective densities of parasitoids of *P. xylostella* in agricultural landscapes.

Keywords Non-crop habitat · Biological control · Landscape composition · Natural enemies · Agro-ecosystems · Ecosystem service · Parasitism · Parasitoid · Spatial scale

Introduction

Natural pest regulation is an important ecosystem service with an estimated value of more than 400 billion dollars (US) per year at a world-wide scale (Costanza et al. 1997). Due to the activity of natural enemies the vast majority of potential arthropod pest species are controlled and do not reach outbreak levels in forest and agro-ecosystems (DeBach and Rosen 1991). A sound natural pest regulation function can therefore contribute to a reduction of pesticide use and the associated adverse environmental effects (Naylor and Ehrlich 1997).

In agricultural landscapes in the temperate zone, the natural pest regulation function is often positively related with the presence of non-crop habitats (Bianchi et al. 2006). These habitats may stimulate natural enemy populations by the provision of

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(alternative) food sources, hibernation habitat and prey or hosts (Landis et al. 2000). As a consequence, non-crop habitats often serve as reservoirs of natural enemies, which can colonize and suppress herbivore populations in arable fields (Tschardt et al. 2005). However, there are many predator and parasitoid species, each with different ecological requirements and potentially different responses to landscape composition (e.g. Elliott et al. 2002; Elliott et al. 1998). In addition, parasitoid responses to landscape composition may vary between years (Menalled et al. 2003). The mechanisms that lead to differential species responses to landscape composition are little understood.

Understanding the spatial dynamics of organisms across landscapes is central to landscape ecology (Wu and Hobbs 2002). Movement of natural enemies and their local population sizes can be affected by many aspects of landscape composition, including the size of habitats (spatial grain), spatial arrangement of habitats, habitat connectivity and quality of habitats and matrix (Tschardt and Brandl 2004; Dunning et al. 1992). In addition, species attributes such as dispersal capacity (e.g. Roland and Taylor 1997), habitat specificity (Wagner and Edwards 2001) and edge crossing behaviour (Duelli and Obrist 2003; Rand et al. 2006), determine how species move in the landscape. Thus, the interplay between landscape composition and species attributes are important determinants for population processes and the spatial distribution of natural enemies in landscapes.

In this study we investigate how parasitoids of the diamondback moth, *Plutella xylostella*, are affected by landscape composition. *P. xylostella* is a pest in cabbage crops throughout of the world (Talekar and Shelton 1993) and in The Netherlands its larval stages are parasitized by *Diadegma* spp. (Bukovinszky et al. 2004). The aim of the study was to assess parasitism rates in field populations of *P. xylostella* larvae and to identify landscape factors affecting the level of biological control of this agricultural pest species.

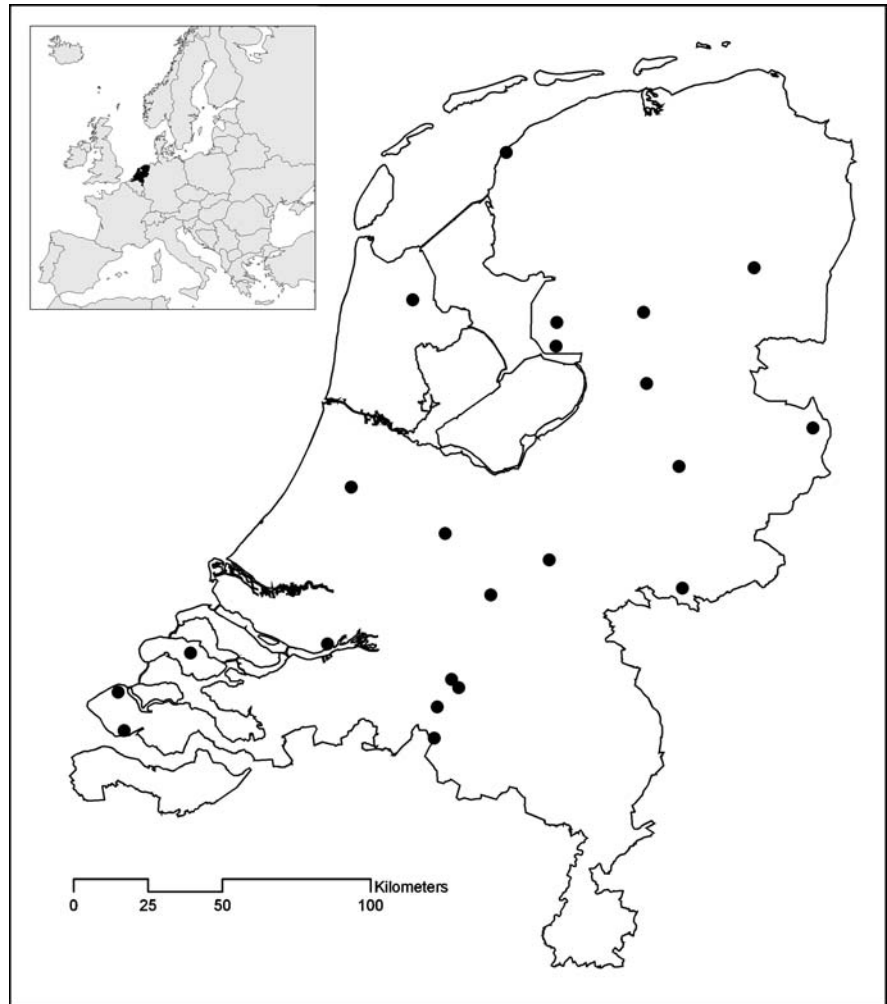
Methods

The study was conducted in 22 organic Brussels sprout fields across The Netherlands in July 2006 (Fig. 1). Brussels sprout is an important horticultural crop in The Netherlands with 3100 ha planted in

2005 (CBS <http://statline.cbs.nl>). It is planted from February till mid April and harvested from August until March. Only organic farms were selected to exclude possible effects of pesticide applications. In each Brussels sprout field, eight potted experimental Brussels sprout plants were put in dishes (6 cm high, 42 cm diameter) that were filled with water and a droplet detergent. Experimental plants were positioned in fields on a line perpendicular to the field edge towards the field centre with 5 m distance between plants. The first plant was placed 5 m from the field edge. There was no leaf contact between experimental plants and Brussels sprout plants in the field. Each experimental plant received 10 second or third instar larvae of *P. xylostella*, which originated from laboratory colonies that were also reared on Brussels sprout. *P. xylostella* larvae were transported to the fields in sealed Petri dishes containing a leaf segment of Brussels sprout. The leaf segment containing the larvae was fixed on the experimental plants with two needles. Two days later, *P. xylostella* larvae were recovered by destructively harvesting of experimental plants. The harvested plants were stored at 4°C and recovered larvae were dissected and checked for the presence of parasitoid eggs within three days.

Parasitism rates were related to weather and landscape variables. Weather variables were recorded daily at the nearest weather station (typically less than 50 km) and included wind speed, mean temperature, relative humidity, mm of rain, and hours of sunshine. In addition, 20 landscape variables were recorded in circles of 0.3, 1, 2 and 10 km diameter around each field using the LGN5 (De Wit and Clevers 2004) and the grid-based Viris database. The habitat types considered were forest, the area of forest edges, nature (all other natural terrestrial habitats), pasture, agriculture (cereal, maize, beet and potato), horticulture, orchards, nurseries, bulb cultivation, water, urban areas and roads. In addition, the length of forest edges, hedges, channels, tree lines, road verges, dikes and field edges, and the number of solitary trees were assessed. Hence, two measures of forest edges were evaluated. The length of forest edges (km) was calculated as the contour of forest patches, whereas the area of forest edge (ha) was calculated as the area of forest in 25 x 25 m grids that contained both forest and non-forest habitat types. We analysed effects of landscape variables for

Fig. 1 Overview of the location of 22 organic Brussels sprout fields in The Netherlands (shaded in the inset map)



individual landscape sectors (i.e. a 0.3 km diameter circle for smallest spatial scale and rings of increasing size for the other three spatial scales) and cumulative landscape sectors (i.e. circles with 0.3, 1, 2 and 10 km diameter).

Parasitism rates were based on the recovered larvae and pupae of *P. xylostella* from harvested plants. Larvae that had fallen into the dishes were discarded, because often no reliable assessment of parasitism could be made. The number of parasitized *P. xylostella* per plant was assumed to follow a binomial distribution. To test this assumption a goodness-of-fit likelihood ratio test was performed for each individual location. This test compares the log-likelihood for a model in which the eight plants have a common probability with the log-likelihood for a model in which each plant has its own

probability. The test statistic equals twice the difference in log-likelihoods and follows, under the null hypothesis of a common probability, a chi-squared distribution with 7 degrees of freedom. Note that in some cases the test statistic has less than 7 degrees of freedom because there were no larvae left on some plants. The independent test statistics can also be summed yielding an overall chi-squared statistic with 147 degrees of freedom.

Effects of weather and landscape variables on parasitism probabilities were analyzed using a GLMM, i.e. a generalized linear mixed model (Breslow and Clayton 1993) with a binomial distribution and logistic link. Ordinary logistic regression could not be used because parasitism counts of individual plants are subject to two levels of variation: variation between fields and binomial variation

within fields. Therefore a random field effect was added to the linear predictor of the logistic regression model, giving a GLMM. In addition, an overdispersion factor was added to the binomial variance to account for the extra binomial variation within fields. The Wald test was used for significance testing of landscape variables. Mean probabilities, e.g. for graphical display of effects, are obtained by integration over the random field effect. Model checking was performed by plotting Pearson residuals against fitted values and no anomalies were found. We tested for curvature by adding a quadratic term to the

generalized linear logistic model for all forest related habitat variables. The quadratic term was never significant at the 5% level. All statistical analyses were conducted with Genstat 10 (GenStat Committee 2007).

Results

In total 812 out of 1760 released *P. xylostella* larvae were recovered from the experimental Brussels sprout plants, which is 46.1%. The mean number of recovered *P. xylostella* per field was 36.9 ± 12.6 (SD). Due to the warm weather, 142 (17.5%) of the recovered *P. xylostella* were pupae. The overall parasitism rate of *P. xylostella* was 23.3% (189/812), with 26.9% (180/670) of the larvae and 6.3% (9/142) of the pupae being parasitized. Parasitism rates differed strongly between locations. The mean parasitism rate per field was $26.8\% \pm 25.3\%$ with minimum and maximum values of 4.0 and 94.1%. The hypothesis that *P. xylostella* on the 8 experimental plants in each field has a common probability of being parasitized is rejected for 5 of the 22 locations ($P < 0.05$). The overall test, however, is very significant indicating that in general there is more variation in parasitism levels between plants in a field than can be attributed to binomial sampling ($\chi^2 = 205.17$; $P < 0.001$).

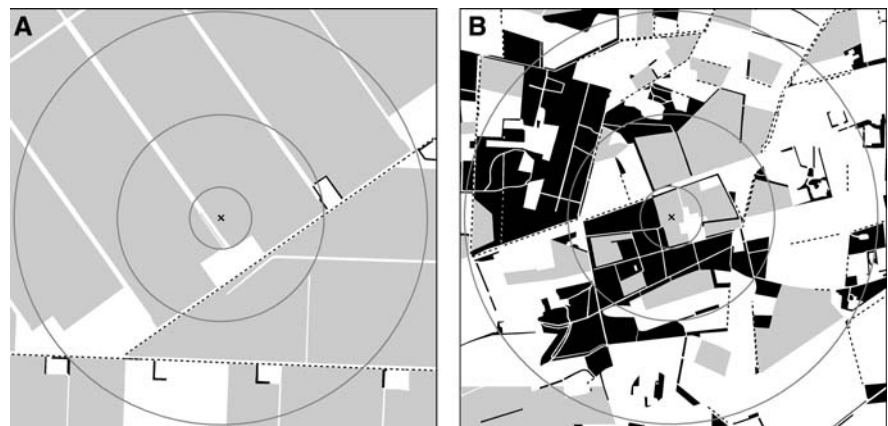
None of the weather variables had a significant effect on parasitism rates in Brussels sprout fields. However, parasitism rates were affected by landscape composition (Table 1; Fig. 2). GLMM analysis on individual landscape sectors (rings) and cumulative

Table 1 Significance levels of landscape variables that have a significant ($P < 0.05$) or marginally significant effect ($0.05 \leq P < 0.10$) on parasitism of *Plutella xylostella*

Predictor	0.3 km	1 km	2 km	10 km
<i>Analysis based on rings</i>				
Area of forest edges	0.085	0.002	0.016	NS
Area of forest	0.086	0.005	0.029	0.034
Length of forest edge	NS	0.016	0.033	NS
Length of road verge	NS	0.021	NS	NS
<i>Analysis based on circles</i>				
Area of forest edges	0.085	0.002	0.007	NS
Area of forest	0.086	0.006	0.016	0.028
Length of forest edge	NS	0.018	0.022	0.086
Length of road verge	NS	0.030	NS	NS

The analysis (in each case a univariate generalized linear mixed model with a single predictor) has been conducted for individual landscape sectors (i.e. a 0.3 km diameter circle for smallest spatial scale and rings for the other three spatial scales) and cumulative landscape sectors (i.e. circles with 0.3, 1, 2 and 10 km diameter, respectively)

Fig. 2 Example of an organic Brussels sprouts fields in a landscape with a small (a) and a large forest area (b). Gray indicates agricultural areas; black indicates forest/hedges and dotted lines represent tree lines. Parasitism rates in (a) and (b) were 7 and 94%, respectively



landscape sectors (circles) indicated significant ($P < 0.05$) positive effects of the area of forest edges (1 and 2 km diameter) and forest (1, 2 and 10 km diameter), as well as the length of forest edges (1 and 2 km diameter) and road verges (1 km diameter) on parasitism rates. Marginal significant effects ($0.05 \leq P < 0.10$) were found for the area of forest edges and forest at 0.3 km diameter and, for the analysis based on cumulative landscape sectors, the length of forest edges at a scale of 10 km (Table 1). The analyses on individual and cumulative landscape sectors resulted in more or less similar significance levels. The area of forest edges at a scale of 1 km was the most significant landscape variable ($P = 0.002$; Fig. 3). Significance levels of the area of forest (edge), the length of road verges and forest edge on parasitism levels were the highest at a scale of 1 km, suggesting that *Diadegma* spp. respond to landscape composition at this spatial scale.

To investigate the possibility that *P. xylostella* parasitism is affected by multiple landscape variables, we assessed whether landscapes variables were significant when added to the univariate model with area of forest edge at a scale of 1 km (using cumulative landscape sectors). There were only two variables that resulted in a significant improvement of the model: horticulture at 0.3 km diameter ($P < 0.032$) and solitary trees at 2 km diameter ($P < 0.023$), whereby horticulture had a positive effect on parasitism and solitary trees a negative effect. The negative effect of solitary trees is somewhat ambiguous because it contradicts with the strong positive effect of forests on parasitism rates of *P. xylostella*.

The estimate of the variance of the added random field effect in the GLMM equaled 1.10 or more, depending on the landscape variable used in the model. An estimate of 1.10 implies that for fields with a mean parasitism probability of 0.5, a 90% prediction interval for individual field probabilities ranges from 0.15 to 0.85.

Discussion

Our study showed that forest and forest edges were positively related with parasitism rates in field populations of *P. xylostella* larvae in Brussels sprout fields (Table 1; Fig. 3). Indeed, forests are considered

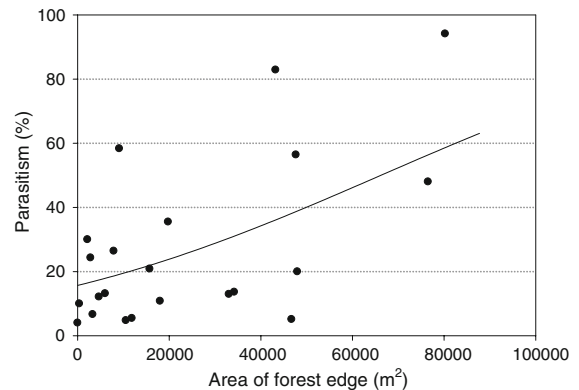


Fig. 3 Observed and fitted relationship between the parasitism rate of *Plutella xylostella* larvae and the area of forest edge at a scale of 1 km. The fitted curve is based on a generalized linear mixed model with only area of forest edge as predictor

important habitats for many parasitoid species (Fraser et al. 2007). Other studies also demonstrated positive effects of wooded habitats on parasitism rates for various insect herbivore species and cropping systems (Marino and Landis 1996; Roschewitz et al. 2005; Schmidt et al. 2003; Thies et al. 2003, 2005; Thies and Tschardtke 1999), but not in all cases (Menalled et al. 2003; Costamagna et al. 2004). The predominantly positive effect of forest on parasitism rates may be explained by the presence of nectar sources, which are often abundant at forest edges, and a more favourable microclimate, which results in higher longevity and reproduction of parasitoids (Dyer and Landis 1996, 1997; Costamagna and Landis 2004; Baggen and Gurr 1998; Winkler et al. 2006). In addition, forests may harbour hosts which may be essential to survive the winter period (Maier 1981). Road verges were also positively related with parasitism rates. These habitats may stimulate parasitoids because of presence of floral nectar and reservoirs of (alternative) hosts. Multiple regression analysis indicated that the area of horticulture also has a potential positive effect on parasitism rates. Horticultural areas may act as sources of parasitoid populations when these habitats support host populations. However, the extent to which nearby cabbage fields act as sources of parasitoids will depend strongly on the local pest management (e.g. chemical control of *P. xylostella*).

We used two measures to quantify the amount of forest edges: the length of forest edges (expressed in km) and the area of forest edges (expressed in ha).

The area of forest edge was calculated as the area of forest in 25×25 m grid cells that besides forest also contained other habitat types. In our analysis the area of forest edges showed in most cases a higher correlation with parasitism rates than the length of forest edges (Table 1). If forest acts as a source of parasitoids, landscape sectors that are dominated by small, linear forest structures only have a limited source area (giving rise to a limited number of parasitoids colonizing fields), but have a relatively large length of forest edge. For such elongated forest patches, the area of forest edge is likely to be a better measure to predict the pest control potential of parasitoids colonizing fields than the length of forest edge. This finding suggests that area-based landscape measures of habitat interfaces may be better descriptors for source-sink dynamics in fragmented landscapes than the length of habitat interfaces.

The binomial goodness-of-fit tests indicate that there is evidence for extra-binomial variation among plants within fields. Several biological mechanisms can attribute to this extra variation. First, during the experiment plants were exposed to different densities of larvae as some larvae fell in the dishes. Parasitoids may have searched plants with high densities of larvae more intensively than plants with lower densities (Wang and Keller 2005). Second, differences in feeding rates or feeding location on the plant may have lead to differential emission of semiochemicals causing some plants to be more attractive for parasitoids than others (Tumlinson et al. 1992). The variance of the random field effect, reflecting the variation between fields, is quite large revealing that parasitism rates can be very different for individual fields with the same mean parasitism probability. This variability is much larger than the extra-binomial variation within fields. The between field variability can be due to yet unknown variables, or it may reflect natural variation in spatio-temporal dynamics of parasitoids.

The population of *Diadegma* spp. is clearly spatially-structured. Given the scattered occurrence of horticultural fields in the agricultural landscapes, it may resemble a metapopulation with habitat islands in a landscape matrix. However, unlike in a classical metapopulation setting, the parasitoid needs to colonize the available patches each year, as hibernation in cabbage fields is unlikely. At the start of the active season, colonization of horticultural fields may occur

from hibernation sites (e.g. forests). Later in the season, horticultural fields where a local parasitoid population has built up may act as sources of migrants. The relevant spatial scale for field colonization is determined by the dispersal distance of *Diadegma* spp., which can be up to 108 m in 5 days and most likely even further after habitat disturbances (Schellhorn and Silberbauer 2002). As dispersal over several days to weeks is plausible, the spatial scales for which we found relations (forest: radius of 500 to 1000 m; horticulture: radius of 150 m) appear to be within the range of potential dispersal distances.

The area of forest edges at a scale of 1 km was the landscape variable with the most significant effect on parasitism of *P. xylostella*. Thies et al. (2003) reported that the parasitoid species *Phradis interstitialis* and *Tersilochus heteroceris* responded to the area of non-crop habitat at spatial scales of respectively 1 and 1.5 km. In another study it was demonstrated that *Aphidius* spp. also responded to landscape composition at a scale of 1 km (Thies et al. 2005). The very limited variation in responses to spatial scale suggests that a range of parasitoids have dispersal capacities in the same order of magnitude. This suggests that a scale of 1 km can be used as a “functional spatial scale” to implement landscape management aiming at enhancing the natural pest control function.

In conclusion, landscapes with large areas of forests and road verges showed the highest parasitism rates in *P. xylostella*. This study shows the crucial role of non-crop habitats for sustaining the natural pest control function in rural landscapes across a nationwide gradient (Bianchi et al. 2006). Therefore, the restoration of cleared non-crop habitats in agricultural landscapes does not only enrich its heritage and aesthetic values, it may also contribute to biodiversity conservation and sustaining the pest control function.

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