Modelling and design of pest suppressive landscapes

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Abstract

Empirical evidence is mounting that the landscape matrix matters for the suppression of pests in agricultural crops. Forested areas and forest edges, for instance, have been associated with higher levels of predation and parasitism on the Lepidopteran pests *Mamestra brassicae* and *Plutella xylostella* in Brussels sprouts in the Netherlands. Suppression of soybean aphid, *Aphis glycines*, in Mid Western US states is positively associated with diversity in the landscape and negatively associated with the acreage of corn. Such spatial correlations reflect sink source dynamics of arthropods between landscape elements in relation to the provision of resources to pests and pest natural enemies. A suite of modelling techniques is available and in development to enable extending these empirical results to realistic spatial images of the distribution of the ecosystem service of biological control over agricultural landscapes in dependence of landscape composition and natural enemy dispersal capacity. Modelling in conjunction with experimentation in real landscapes is needed to define realistic targets and expectations for landscape-based biological control in field crops.

Media summary

Non crop habitats in agricultural landscapes provide ecosystem services to agriculture in the form of pollination and biological pest suppression. Insight in spatial dynamics of pests and pest natural enemies across the landscape can be used to generate ecosystem service maps that support landscape design and land use policy.

Key words

Landscape design, biological pest control, spatially explicit simulation models, predator-prey interaction

Introduction

Natural pest regulation is an important ecosystem service with an estimated value of more than 400 billion 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 forests and agro-ecosystems (DeBach and Rosen 1991).

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 (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.

Interest is increasing in the design of landscapes that maximize biological control as a free "public" ecosystem service, thus helping make agriculture less dependent on technological inputs (Fiedler *et al.*, in press). Numerous empirical studies have shown significant effects of the landscape context on biological control in real landscape settings (Tscharntke & Brandl 2004; Tscharntke *et al.* 2005; Bianchi *et al.*, 2006). Spatially explicit simulation models for natural enemy movement and impact in artificial and real landscapes can help to elucidate the cost-benefit ratio of landscape manipulations aiming at higher levels of the ecosystems service of biological control (Zhang, 2007).

Methods

Empirical studies with sentinels in real landscapes

Convincing evidence that landscape composition affects biological control is provided by studies with sentinels. For instance, Bianchi *et al.* (in press) placed second and third instar larvae of the diamond back moth, *Plutella xylostella,* as sentinels on experimental Brussels sprout plants in twenty two fields in different landscapes throughout the Netherlands in July 2006. After two days of exposure, the *P. xylostella* larvae were recovered, dissected and checked for the presence of parasitoid eggs.

Landscapes in a 10 km circle around each sentinel site were digitized using ArcGIS (Fig. 1). 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. Regression was then used to detect associations between landscape variables and percentage parasitism.

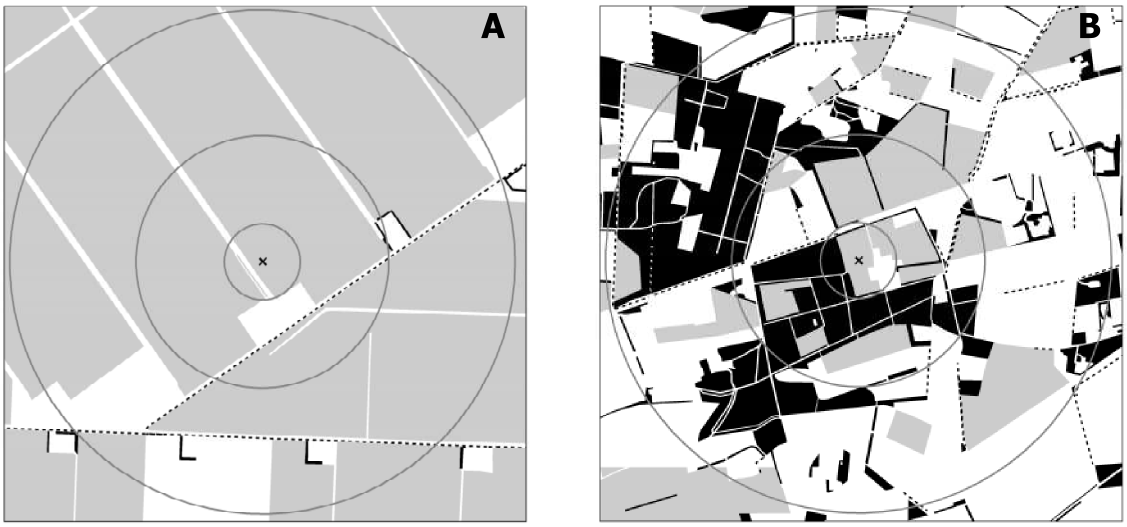

Fig. 1: Example of organic Brussels sprouts fields in a landscape with a small (A) and a large forest area (B). Gray indicates agricultural areas; black indicates forest/hedges and dotted lines represent tree lines. Parasitism rates in (A) and (B) were 7 and 94%, respectively (Bianchi *et al.*, in press).

A similar approach was used by Gardiner *et al.* (submitted) to study the effect of landscape on biological control of the soybean aphid, *Aphis glycines.* In addition, at each site, they made a comparison of the population growth of soybean aphid on plants that were exposed to predators, and plants that were shielded from the impact of predators by insect proof netting over a period of 2 weeks.

Modelling

In silico studies can be made in many different ways. One novel approach is based on the estimation of spatial probability distributions of natural enemy impact from sentinel data (Van der Werf *et al.*, in press).

By combining the estimated kernel functions with landscape maps, maps of impact across the landscape can be made (Baveco *et al.,* in press). A second approach for *in silico* studies is based on estimating an initial effect of predators by exclusion (Gardiner *et al.*, submitted) and extending this effect over a whole growing season using a validated model for pest population growth (Costamagna *et al.*, 2007). A third approach is based upon modelling the predator & prey population processes from the bottom up, i.e. on the basis of detailed description of individual processes (Bianchi & van der Werf, 2003, 2004; Bianchi *et al.,* 2007).

Results

In the *P. xylostella* sentinel study of Bianchi *et al.* (in press), it was found 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

Based upon the data of Bianchi *et al.*, spatial probability distributions of natural enemy impact were estimated by van der Werf *et al.* (in press) and these kernels were then used to create maps of expected parasitization of *P. xylostella* in an agricultural landscape in the Netherlands (Baveco *et al.*, in press).

In their study of landscape effects on soybean aphid, Gardiner *et al.* (submitted) found a significant ($P<0.01$) positive relationship between land use diversity within a 1.5 km radius around the sentinel, and biological control at the sentinel. A strong negative relationship ($P<0.001$) was found between the corn acreage around a sentinel site and biological aphid control on the sentinel. On average, aphid populations were reduced by 79% on plants that were exposed to predators, compared to plants that were shielded from predators and where aphid population growth was essentially exponential. These proportions reduction translate into small but significant savings in crop protection costs for growers that use pesticides (Landis *et al.*, in prep.). For organic growers, these differences represent vast differences in attainable revenue.

Process based landscape simulations, such as those presented in Bianchi & van der Werf (2003, 2004) and in Bianchi *et al.* (2007), allow analysis of what would constitute optimal landscapes for providing biological control. Although such simulations are presently subject to large uncertainties, primarily due to fragmentary knowledge on the movement of pest natural enemies across landscapes and habitat use by beneficial insects, they do help to elucidate basic design characteristics of pest suppressive landscapes. For instance, linear non-crop elements are more effective than square elements of the same area in providing ecosystem services because they shorten the average distance that a natural enemy would have to move from a resource habitat to a crop (Bianchi & van der Werf, 2003). Simulations indicate that fragmentation of non-crop habitats can limit the provision of ecosystem services if the area of natural habitat is low, whereas at higher levels of non crop habitat density, fragmentation may help to overcome dispersal limitations of natural enemies (Bianchi & van der Werf, 2003).

Conclusion

The current challenge is to use our insight in the spatial dynamics of pest organisms and their natural enemies, in conjunction with insights in predator-prey dynamics, to predict the impact of natural set-aside areas as a source of the ecosystems service of natural pest suppression in field crops. Simulations of the spatio-temporal interplay between pests and their enemies in spatio-temporally varying landscape mosaics may be used to increase understanding and appreciation of the effect of landscape design on pest-enemy interactions. Movement of enemies and pests across the landscape can be measured by a suite of techniques, including mark recapture (Schellhorn *et al.,* 2000; van der Werf *et al.,* 2000) and the estimation of kernels from sentinel data (van der Werf *et al.*, in press). Maps can be drawn, based on process based spatially explicit modelling or empirical data, to show the provision of the ecosystem service of biological control across the landscape. Economic analyses can be added to simulations and simulated or empirical maps to weigh costs and benefits (Zhang, 2007). Such simulations and ecosystem service maps may assist in land use planning and land use policy.

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