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Agricultural landscape structure affects arthropod diversity and arthropod-derived ecosystem services

Matthew G.E. Mitchell[a,*], Elena M. Bennett[b], Andrew Gonzalez[c]

[a] Department of Natural Resource Sciences, McGill University, Ste.-Anne-de-Bellevue, QC H9X 3V9, Canada
[b] Department of Natural Resource Sciences & McGill School of Environment, McGill University, Ste.-Anne-de-Bellevue, QC H9X 3V9, Canada
[c] Department of Biology, McGill University, Montreal, QC H3A 1B1, Canada

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ABSTRACT

Knowledge of how landscape structure impacts the diversity and abundance of beneficial and harmful arthropods, pest regulation, and ultimately crop yield has the potential to significantly improve management of agricultural landscapes. We examined how landscape structure in southern Québec affected soybean herbivores, predators of aphids, pest regulation including aphid and herbivory regulation, and crop production. Local-scale field characteristics and landscape structure at distances less than 2 km around each field were the most important predictors for these variables. Increasing field width consistently decreased arthropod diversity and abundance for both predators of aphids and soybean herbivores, but the effects of these changes on pest regulation were inconsistent. Increased field width resulted in less damage to soybean plants from herbivores; but in contrast, aphid numbers were greatest in more complex landscapes where fields were generally narrower. Distance-from-forest within fields and no-till planting methods also decreased pest regulation. Despite these results, soybean yield was not strongly related to pest regulation and instead varied most with distance-from-forest. Thus, patterns of arthropod diversity and abundance may not necessarily coincide with those of pest regulation or crop yield.

1. Introduction

Changes to the structure of agricultural landscapes have the potential to alter arthropod-provided ecosystem services such as pest regulation and pollination. These services depend on the movement of arthropods across agricultural landscapes at different scales (Kremen et al., 2007; Mitchell et al., 2013), as well as the abundance and diversity of the arthropods that provide them (Letourneau et al., 2009; Tscharntke et al., 2005). Agricultural landscape structure, which includes the configuration and composition of crop and non-crop habitats, is expected to influence ecosystem service provision because it is known to affect arthropod movement, abundance, and diversity (Bianchi et al., 2006; Chaplin-Kramer et al., 2011). Forests, meadows, hedgerows, and field margins all provide resources and habitat connectivity for different arthropod groups, including natural enemies of crop pests. Thus, it is commonly predicted that pest regulation will be greater in landscapes that contain a greater proportion or diversity of these habitats (Bianchi et al., 2006; Chaplin-Kramer et al., 2011). Currently, we lack a detailed understanding of how different components of landscape structure simultaneously influence arthropod herbivores, their predators, and associated ecosystem services; the spatial scales at which this occurs; and the effects, if any, on crop production (Chaplin-Kramer et al., 2011).

Most studies of landscape structure and pest regulation focus on landscape complexity, measured as the proportion of non-crop habitat (Batáry et al., 2011), the diversity of habitats present (e.g., Fabian et al., 2013; Gardiner et al., 2009), or the presence of linear elements such as hedgerows (e.g., Holzschuh et al., 2010). The majority of these studies find positive effects of increased complexity on the abundance of beneficial arthropods (Bianchi et al., 2006; Chaplin-Kramer et al., 2011). Non-crop habitat provides foraging, nesting resources and overwintering habitat (Dennis et al., 2000); refuge from predators (Martin et al., 2013); and favorable environmental conditions for many arthropod species (see Bianchi et al., 2006 for a review). Additionally, linear elements such as hedgerows and field margins can provide critical landscape connectivity, both between non-crop habitat patches (van Geert et al., 2010), and between non-crop and crop patches (Bianchi et al., 2010; Segoli

* Corresponding author. Current address: School of Geography, Planning and Environmental Management, The University of Queensland, Brisbane, QLD 4072, Australia. Tel.: +61 (0)7 3346 1643; fax: +61 (0)7 3365 6899.
E-mail addresses: m.mitchell@uq.edu.au (M.G.E. Mitchell), elena.bennett@mcgill.ca (E.M. Bennett), andrew.gonzalez@mcgill.ca (A. Gonzalez).

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and Rosenheim, 2012). For example, increased edge density in wheat fields increases the abundance of herbivore-predating wasp species across the landscape (Holzschuh et al., 2010).

However, the actual benefit from pest regulation that farmers receive in their fields depends not only on the top-down control of pests by arthropod predators, but also on levels of colonization by crop herbivores. The structure of the surrounding landscape can influence both of these processes with important consequences for pest regulation. Therefore, correctly measuring pest regulation as an ecosystem service means including measures of both predator and herbivore pressure on crops relative to their maximum levels in the landscape, and understanding how landscape structure affects both variables (Chaplin-Kramer et al., 2011). Yet, studies investigating how landscape structure or complexity affects both predators and herbivores are rare (Bianchi et al., 2006; Martin et al., 2013).

Landscape structure can also affect predator diversity and ecological theory predicts that more functionally diverse predator groups will show increased niche complementarity (Hooper et al., 2005); different species will attack herbivores in a greater diversity of ways through space and time, leading to increased pest regulation. There may also be a 'sampling effect,' where more diverse communities are increasingly likely to contain the most effective predator for a given herbivore species (Tscharntke et al., 2005). Understanding how the diversity of these different arthropod groups interacts with landscape structure to alter pest regulation is therefore important for the management of agricultural systems.

Effective management of landscape structure to maximize pest regulation also depends on identifying relevant ecological and management scales. Landscape structure effects operate at different scales for different arthropod groups, depending on their mobility and size (Tscharntke and Brandl, 2004). In particular, herbivores, parasitoids, and specialized predators are thought to be influenced by landscape structure at smaller scales than generalized predators (Tscharntke and Brandl, 2004). In many cases, the relationships between landscape structure and arthropod abundance or diversity are strongest at specific scales (Rusch et al., 2011) or are influenced by multiple scales (Chaplin-Kramer and Kremen, 2012; Holzschuh et al., 2010).

Soybean fields (*Glycine max*) provide an ideal system to investigate the effects of landscape structure on arthropod diversity, abundance, and ecosystem service provision. The predominant pest of soybean crops in North America is the soybean aphid (*Aphis glycines*), an introduced species from Asia. Aphids overwinter on native shrubs (*Rhamnus* sp.) in forest fragments and hedgerows, and disperse locally into nearby fields (Ragsdale et al., 2004), as well as over longer distances via atmospheric movements (Ragsdale et al., 2011). A diverse community of arthropod predators, including spiders (Costamagna and Landis, 2007), is thought to be key in controlling soybean aphid populations (Costamagna and Landis, 2006; Mignault et al., 2006). Soybean plants are also damaged by a diverse group of arthropod herbivores (Kogan and Turnipseed, 1987). Yet the effects of landscape structure on the community of predators that control aphids, the aphids themselves, other generalist herbivores, and the resulting provision of pest regulation service and disservices, have been rarely studied in combination (Ragsdale et al., 2011).

We evaluated the effects of both local and broad-scale landscape structure, as well as crop planting techniques and forest plant diversity, on the provision of pest regulation and crop production in soybean fields east of Montréal, Québec, Canada. Specifically, we asked: (1) how does landscape structure, and in particular field structure, affect the diversity and abundance of arthropods that provide key pest regulation services and disservices, (2) at what scales does this occur, and (3) how important are changes in landscape and field structure, and arthropod abundance and diversity, for pest regulation and crop production?

2. Methods

We conducted our study in 34 commercial soybean fields (2010: $n = 15$, 2011: $n = 19$) within the Montérégie east of Montréal (45°30′ N, 73°35′ W), Québec. This region consists of fragmented forests (21% forest) surrounded by a matrix of agricultural fields (55% agriculture) dominated by corn (48% of cultivated area), soybean (26%), and hay fields (8%; Mitchell, unpublished data). Soybean in this region is planted using either conventional tillage or no-till practices in a yearly rotation with corn, therefore new fields were chosen each year. Agricultural fields in Québec follow the seigneurial system of land distribution, and are arranged in long narrow strips running from adjacent remnant forest fragments. Each field can therefore be seen as a transect where distance-to-forest varies but other landscape and management variables are uniform. Fields are generally oriented on a northwest-southeast bearing.

Our soybean fields spanned the range of crop-dominated to forest-dominated landscapes present in this region. Fields were originally chosen according to the size and isolation of their adjacent forest patch for a prior study (Mitchell et al., 2014). Around each field in circles of increasing radii (i.e., 0.5, 0.75, 1.0, 1.5, 2.0, 3.0, 4.0, and 5.0 km), we quantified the proportion of forest and the ratio of field perimeter to field area using available geospatial datasets (Système d'Information Écoforestière & Base de Données des Cultures Assurées) in ArcGIS 9.3.1. Using the same spatial datasets, we also measured field width and the orientation of each field from its adjacent forest fragment (i.e., NW or SE). Soybean planting method was assessed visually for each field. To estimate plant diversity in the forest fragment next to each field, we established a single 20 m × 20 m square quadrat directly adjacent to each soybean field and identified each tree and shrub species present.

2.1. Measurement of arthropod diversity and abundance

Within each field, we established two sampling locations for arthropod diversity and abundance, pest regulation and crop production, one each at 0 m and 500 m from the adjacent forest fragment. Potential predators of aphids and soybean herbivores were collected at each distance-from-forest twice each growing season (2010: July 27–30 and August 9–13; 2011: August 1–5 and 17–20) using 100 figure-eight sweep net movements (Mignault et al., 2006) with a 30 cm diameter insect net along a transect parallel to the field-forest edge. Captured individuals were placed in 85% ethanol solution until identification. All individuals were sorted to morphospecies (Oliver and Beattie, 1996) and then classified to family, except for Coccinellidae and Lepidoptera larvae, and Orthoptera. For predators of aphids and soybean herbivores, individuals were classified to genus; we assume taxonomic sufficiency of this level of classification (Pik et al., 2009; Timms et al., 2012). Araneae individuals were also counted, but were not classified further.

2.2. Measurement of ecosystem services

At the same time as the sweep net collections, we estimated two components of pest regulation: aphid regulation and herbivory regulation. We defined pest regulation broadly, and used indicators that simultaneously measured landscape effects on the colonization of fields by aphids and soybean herbivores and control of these groups by arthropod predators. Indicators for each component, aphid numbers and arthropod herbivory (proportion