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Abstract: Biological control of pests by their natural enemies is considered a key process to reduce pesticide use in modern agricultural systems. Diversity of natural enemies and pest control levels have been shown to be enhanced in organic farming systems and in landscapes with high amount of semi-natural habitats, but the role of organic farming at the landscape scale remains little explored, especially on pest control levels. We investigated the effects of organic farming at the field and landscape scales on the diversity of predatory arthropods and on pest predation levels in 20 pairs of cereal crops located in bocage landscapes with varying proportion of area covered by organic farming in western France. Our results confirmed a strong effect of farming system at the field scale on arthropod diversity but not on pest predation levels. Arthropod diversity and pest predation were little or not influenced by organic farming at the landscape scale, but in some cases, by land-use diversity, grassland area and hedgerow densities. Our results suggest that the promotion of biological control in bocage landscapes might rely on both the local adoption of organic practices and on the maintenance of hedgerow habitats.

Key words: farming systems, landscape context, carabid beetles, ladybirds, aphid and weed predation, hedgerows.

Introduction

Enhancing biological control of crop pests by their natural enemies is considered a promising strategy to increase the sustainability of agricultural production systems. Diversity of natural enemies and pest regulation processes were found to be enhanced in fields or farms under organic farming (OF) compared to conventional ones (CF) (Bengtsson *et al*., 2005). Landscape heterogeneity or complexity, expressed in most cases as the amount of semi-natural habitats (SNH), is another important driver of diversity of natural enemies and pest control levels (Bengtsson *et al*., 2005; Bianchi *et al*., 2006).

Recently, it has been suggested that landscape heterogeneity related to farming systems might also impact biodiversity and ecological processes (Vasseur *et al*., 2013). The few studies addressing this issue have found a higher diversity of natural enemies and pests in landscapes with high proportion of area covered by OF (e.g. Gabriel *et al*., 2010). However, the effect of both proportion and configuration of OF remains little explored, especially on pest control levels.

The aim of the present study was to investigate the effects of OF at the field and landscape scales on diversity of predatory arthropods (carabid beetles and ladybirds) and prey predation levels (aphids and weeds) in cereal crops. This question was addressed using data from two surveys conducted on a network of organic and conventional farms in northwestern France.

Material and methods

Study area and field selection

Our study took place in 'bocage' landscapes in Brittany, northwestern France, characterized by a high density of hedgerows and mixed crop-livestock farming. The main crops are grassland (40 %), maize (30 %) and wheat (20 %). Sampling was conducted in 20 pairs of OF and CF cereal fields, distributed along a landscape gradient characterized by a high variability in the proportion of OF (from 1 to 44%, calculated in 1000m diameter circles centered around studied fields), and by a lower variability in the amount of SNH (hedge density from 1 to 2%) (Puech et al. 2015).

Biological sampling

Arthropods were sampled in each field in 2012 and 2013, at least 10 m away from field edges to avoid edge effects. Carabid beetles were collected using four pitfall traps during six sampling periods (one week each). Adult ladybirds were caught with sweep nets (with 500 sweeps per field) during four sampling sessions. Data were pooled over sampling sessions to work out total species richness and abundances/activity-densities of arthropods in each field. Pest predation levels were measured using two types of sentinel preys - pea aphids (*Acyrthosiphon pisum*) and seeds of field pansy (*Viola arvensis*) - exposed during three sessions in 2016 in each field. For each session, four cards with 5 aphids were exposed during 24h at the top of cereal plants, and four cards with 10 seeds were exposed during 5 days at the bottom of the same plants. The number of predated and exposed prey items were counted to estimate predation rates of aphids and seeds.

Landscape description

Aerial ortho-photographs and field surveys were combined to digitize land-uses (grassland, annual crops, woodland, urban areas), hedgerows, and type of farming system (OF vs. CF) for each agricultural field in a 1km diameter circle centered on each sampled field. Several composition and configuration metrics were calculated at three spatial scales (in 250m, 500m and 1000m diameter circles) to describe the heterogeneity (i) related to SNH and other land-uses, and (ii) related to farming systems (Table 1).

Table 1. Composition and configuration metrics calculated to describe landscape heterogeneity related to SNH and land-uses, and to farming systems.

Type of heterogeneity	**Heterogeneity component**	
	Composition	**Configuration**
SNH and land-uses	Proportion (%) of land-uses, land-use diversity	Hedge density (%), mean patch size (ha)
Farming system	Proportion (%) of OF	Edge length between OF & CF (m)

Statistical analysis

Generalized Linear Mixed Models (GLMm) were used to test, in a first step, the effects of local farming type (OF *vs*. CF) and landscape metrics on arthropod diversity and predation rates. Separate models were built for each type of landscape heterogeneity (SNH + land-uses *vs*. farming systems) and each spatial scale (250m, 500m, 1000m). In a second step, analyses were performed separately for OF and CF fields to account for possible interacting or confounding effects between local farming type and landscape heterogeneity. For each analysis, multi-model inference and model averaging were used to build all possible combinations of explanatory variables and to determine the average of models presenting similar relevance (ΔAICc < 2).

Results and discussion

Effects of farming systems at the field scale

Our results confirmed a strong positive effect of field scale OF on species richness and abundances or activity-densities of predatory arthropods in cereal fields (Figure 1), probably because of higher resource quality and absence of pesticide use in OF fields. On the contrary, predation rates of aphids and seeds were similar in OF and CF cereal fields, which contrasts with earlier studies reporting higher pest control levels in OF systems (e.g. Winqvist et al. 2011). The lower prey availability for arthropods in CF fields might have led to higher predation of exposed preys in these fields.

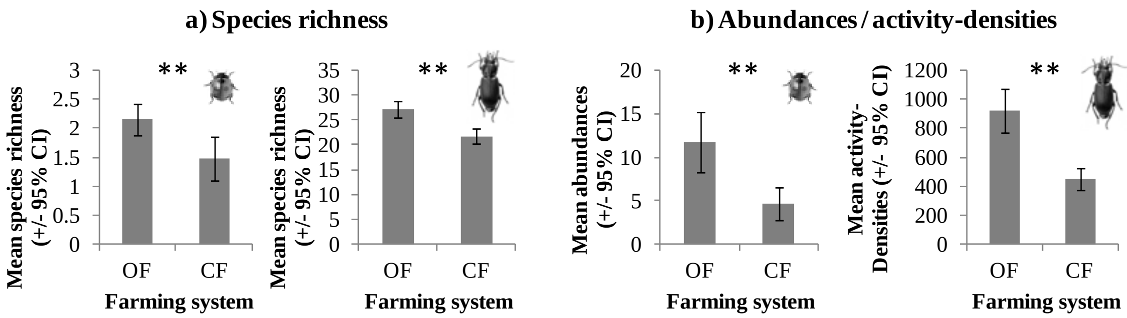

Figure 1. Average abundances/activity-densities (± 95% CI) of ladybirds and carabid beetles in OF and CF fields. ** : significant effect identified in GLMm.

Effects of landscape heterogeneity related to farming systems and SNH

Overall, farming system heterogeneity had little effect on arthropod diversity and no significant impact on prey predation levels (Table 2). Complex configuration of OF and CF (high edge length) resulted in increased ladybird abundances in OF fields, but reduced ladybird abundances in CF fields (Table 2). These contrasting findings could reflect different processes related to the high attractivity of OF fields for arthropods: colonization of the studied OF fields by surrounding OF crops (source effect) *vs*. dispersal from the studied CF fields to surrounding, more suitable OF fields (dilution processes). The lack of effect of farming heterogeneity on pest predation might be due to similar prey predation levels in studied OF and CF fields.

In addition, heterogeneity related to SNH and other land-uses influenced predatory arthropods and prey predation in specific cases. Ladybird abundances increased in CF fields surrounded by a high hedgerow density (250m), suggesting a positive role as refuge or overwintering site of hedgerows. By contrast, arthropod abundances and seed predation were reduced in fields located in landscapes with high land-use diversity, which contrasts with existing literature (e.g. Gardiner *et al*. 2009). Seed predation was further reduced in CF fields surrounded by large area of grassland. In the study area, landscapes with diverse land-uses are characterized by more grassland fields and relatively litte cereal cultivation. This lower availability of crop habitats might explain the lower arthropod abundances and lower seed predation levels.

Table 2. Overview of effects of landscape metrics (in 250m, 500m, 1000m diameter circles), identified in averaged GLMm on arthropod abundances/activity-densities and prey predation rates in OF and CF fields. (+) or (-) indicates positive or negative effect; *n.s.*: no significant effect. LUD: land-use diversity, HD: hedge density, GR: grassland, OF-CF: edge length between OF and CF.

Type of heterogeneity	**Fields**	**Abundances / activity-densities**		**Predation rates**	
		Ladybirds	**Carabids**	**Aphids**	**Seed**
Farming systems	OF	OF-CF 500m (+)	*n.s.*	*n.s.*	*n.s.*
	CF	OF-CF 1000m (-)	*n.s.*	*n.s.*	*n.s.*
SNH & land-uses	OF	*n.s.*	LUD 250m (-)	*n.s.*	LUD 250m (-)
	CF	HD 250m (+) LUD 500m (-)	*n.s.*	*n.s.*	% GR 250m (-) % GR 500m (-)

Conclusion and perspectives

Our study suggests that the promotion of predatory arthropods in bocage landscapes will rely on both the local adoption of organic practices by farmers, and the maintenance of hedgerows on farms. However, further investigation is needed to better understand the interactions between farming systems and landscape heterogeneity on pest predation levels. Synchronic analyses of the relationships between arthropod diversity and predation levels measurements are especially needed.

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