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Effect of crop management and landscape context on insect pest populations and crop damage

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ABSTRACT

Understanding the determinants of insect–plant interactions and pest population dynamics at multiple spatial scales is a pre-requisite for developing innovative crop protection strategies and increasing the sustainability of agroecosystems. In a two-year study, we investigated the relative influence of local crop management and landscape context on pollen beetle (*Meligethes* spp.) abundance and damage at 8 different spatial scales around 42 oilseed rape fields using a multi-model inference approach. We found that pest abundance was mainly determined by the proportion of grassland and woodland in the landscape at scales ranging from 1500 m to 2000 m. Pollen beetle damage was affected both by local management and landscape predictors at scales ranging from 1500 m to 2000 m. Indeed, damage was negatively correlated with the nitrogen nutrition index of the plants and positively correlated with the proportion of woodland in the landscape at a large scale. Our multi-scale approach revealed that landscape complexity determines pollen beetle abundance in the spring and that nitrogen nutrition of the plants influences crop ability to compensate bud abortions resulting from pest attacks. The results are discussed in relation to crop management, pest dispersal ability and landscape structure.

1. Introduction

Pest management strategies have traditionally been developed at the field scale and have often relied on the use of broad-spectrum pesticides. In today's socio-economic context, developing ecologically sound pest management strategies has become a major and urgent concern as the intensive use of agrochemical inputs is recognized to have detrimental impacts on the environment (Stoate et al., 2001). Understanding the determinants of insect–plant interactions and pest population dynamics is a pre-requisite for developing innovative crop protection strategies and increasing the sustainability of agroecosystems.

The importance of multiscale approaches in understanding population dynamics and trophic interactions has long been emphasized (Wiens, 1989; Levin, 1992). Insect populations inhabiting fragmented landscapes are generally considered as interconnected subpopulations functioning as a source-sink system (Hanski, 1999; Tscharntke and Brandl, 2004). These populations can be affected by multiple factors operating at various scales (Ricklefs, 1987; Clough et al., 2007). At the field scale, the richness and abundance of insect species depend on local habitat characteristics which are largely determined by crop management. Indeed, crop management techniques such as soil cultivation, agrochemical applications or plant species diversity are known to influence habitat quality and thus arthropod movement and survival (Landis et al., 2000; Thorbek and Bilde, 2004). At larger scales, recent studies have pointed out that the richness and abundance of local species are strongly affected by landscape context, especially for high dispersive organisms and multiple habitat species (Weibull et al., 2003; Aviron et al., 2005; Purtauf et al., 2005; Tscharntke et al., 2007). While the most relevant scale for studying relationships between the surrounding landscape (*i.e.* proportion or distribution of specific habitats in the landscape) and insect species richness or abundance depends on species biology and characteristics (*e.g.* dispersal ability), conclusions made from any single spatial scale may change when integrating processes operating at larger or finer scales (McGeoch and Price, 2005; Tscharntke et al., 2005; Rusch et al., 2010). Therefore, recent studies have emphasized that understanding pest population dynamics in agroecosystems requires a spatial perspective and should consider both local conditions and landscape context (Bianchi et al., 2006; Rusch et al., 2010). However,

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while studying relative crop management and landscape context influences at different spatial scales seems to be relevant for developing alternative pest management strategies, such approaches are still rare (but see Zaller et al., 2008a; Eilers and Klein, 2009).

Pollen beetle is among the major insect pests of oilseed rape (*Brassica napus* L.) (OSR) in Europe and implies considerable pesticide applications (Alford et al., 2003). After emergence from overwintering areas, adults migrate onto OSR fields to feed on pollen and oviposit in buds thereby inflicting severe yield losses (Nilsson, 1994). During the past decade, insecticide-resistance in pollen beetle populations has been an increasing and rapidly spreading phenomenon in many European countries (Detourne et al., 2008). Hence, the control of pollen beetle populations has become a major concern for farmers, highlighting the need to develop innovative pest management strategies. At the local scale, pollen beetle abundance and damage have been found to be affected by various farming practices. Valantin-Morison et al. (2007) found that damage resulting from pollen beetle attacks was negatively related to nitrogen availability in the soil and to crop density due to compensation abilities of the OSR plant. Moreover, because nitrogen fertilization influences emissions of crucifer-specific olfactory cues involved in host plant location (*i.e.* glucosinolates and their degradation products: isothiocyanates), crop nitrogen status may modify plant attractiveness, thereby affecting pest abundance in the field through bottom-up effects of resource quality (Evans and Allen-Williams, 1994; Smart and Blight, 2000; Staley et al., 2010). At the landscape scale, visual and odor cues were found to affect the dispersal of pollen beetle which was able to move several kilometers (up to 12 km in two days) from the release point to locate the host plant (Stechmann and Schutte, 1976; Williams et al., 2007). Moreover, it has been found that landscapes with high proportions of semi-natural habitats tend to support lower populations of pollen beetle than simple landscapes do, due to higher top-down control by parasitoids (Thies et al., 2003). Thus, in an integrated pest management perspective both crop management and landscape context have to be taken into account together in order to identify and rank the relative importance of local and landscape predictors and their relative scales on pest population dynamics.

An increasing body of recent literature in ecology and agroecology has focused on the effect of landscape context on various organisms including pests and their natural enemies (Bianchi et al., 2006). Such studies usually assess the role of landscape variables using multiple regression with stepwise selection procedures (Whittingham et al., 2006). However, recent papers have pointed out the limitations of stepwise selection including bias in parameter estimations, variability in variable selection depending on the procedure used and the data set, and uncertainty of the results due to inference on a single best model (Stephens et al., 2005; Whittingham et al., 2006). We applied here a multimodel inference approach which made it possible to compare models with all possible combinations of predictors of the full model to identify and rank relevant variables. Such an approach does not suffer from limitations associated with stepwise selection techniques and provides robust parameter estimates and predictions (Johnson and Omland, 2004; Whittingham et al., 2006).

The aim of this multi-scale study is to explore the relative importance of crop management and landscape context on pollen beetle abundance and crop damage and to identify relevant spatial scales for the development of integrated pest management strategies. In particular, we address the following questions: (i) Do crop management at the local scale and landscape structure at larger scales affect pest population density and damage in the field? (ii) In regard to pest population dynamics, is landscape context influence more important than bottom-up effects of local crop management? (iii) Does the influence of predictors on populations and damage change across scales when integrating both local and landscape variables? (iv) What spatial scales are the most important for explaining pollen beetle abundance and damage?

2. Materials and methods

2.1. Study site and experimental design

The study was carried out in the northwest of France in the Haute-Normandie region (49°25′N, 1°12′E). The landscape is characterized by little fragments of semi-natural habitats distributed among agricultural areas. In this region the main crops are cereals (75% of arable land area), oilseed rape (15%), sugar beet (4%), potato (2%) and high protein crops (2%). The semi-natural habitats consist of small woodlots, hedgerows and grasslands. This area is located in a sub-oceanic climate zone (Table 1).

A set of 42 oilseed rape fields was selected over two years (23 fields in 2008 and 19 fields in 2009). For each year, OSR fields were distributed between two sites within the region (site A: Eure county, and site B: Seine-Maritime county). The two sites were chosen in relation to the areal proportion grown under winter OSR within each site: site A supports large amounts of OSR whereas site B supports small amounts of OSR (Table 1). In each site, the fields were selected according to the OSR cultivar, the landscape context and spatial independence between fields. Following the methodology of Thies et al. (2003), the fields were chosen to build a gradient of complexity in each site, ranging from simple and open landscapes (*i.e.* <3% of semi-natural habitats) to more complex and closed landscapes (*i.e.* up to 58% of semi-natural habitats) (Table 1). Because landscapes were analyzed in a 2000 m radius around each field (see Section 2.2), we selected fields at least 4 km apart in order to consider non-overlapping landscapes as study units (Tischendorf and Fahrig, 2000).

2.2. Local crop management variables and landscape metrics

Interviewing all participating farmers made it possible to record relevant crop management variables of each focus field such as sowing date, amount of nitrogen fertilizer, pesticide applications, preceding crop and soil cultivation techniques. For each field, OSR plant density and aboveground aerial biomass were measured the same day at two different periods: (i) in early spring during bud development stage (*i.e.* end of March – Growth Stage GS 50) from six 0.5 m^2 microplots and (ii) in early summer during seed development stage (*i.e.* mid-June – GS 80) from six 1 m^2 microplots. Dry biomass (after 48 h of drying at 80 °C) and nitrogen content of the early spring samples were determined using the Dumas method (Bremner, 1996). The Nitrogen Nutrition Index (NNI), which is a good indicator of crop nitrogen status (Colnenne et al., 1998), was then calculated following Lemaire et al. (1997) (1):

$$\mathrm{NNI} = \frac{N_t}{N_c} \tag{1}$$

where N_t is the total nitrogen concentration measured in the aerial parts, and N_c the critical nitrogen concentration for the same shoot biomass calculated using the relationship established by Colnenne et al. (1998) (2):

$$N = 4.48W^{-0.25} \tag{2}$$

where W is the shoot biomass expressed in t ha^{-1}.

Based on aerial photographs (BD ORTHO®, IGN, 2004, pixel size: 0.5 m) and intensive field inspections, we manually digitalized the land use around each field and quantified the total area of each habitat type using ArcGis software (Version 9.2, ESRI). Habitat types were classified into 22 categories: arable land (16 different crop types), grassland (meadows and fallows), hedgerow, woodland,