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Relative effects of local management and landscape heterogeneity on weed richness, density, biomass and seed rain at the country-wide level, Great Britain

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ABSTRACT

Weed management is a critical issue as it is faced with a daunting set of challenges linked to crop productivity and farmland biodiversity. Developing new strategies for weed management requires a clear understanding of the relative role of local management and landscape heterogeneity on weeds. Yet few studies have investigated the combined effect of these factors on a variety of weed metrics that reconcile agronomical and ecological aims. Here, we analyzed the relative role of local management intensity and landscape heterogeneity according to the distance to field margin on four weed metrics (species richness, density, biomass and seed rain) and community composition in 257 fields (beet, maize, spring and winter rape fields) across Great Britain. Generalized mixed effect models followed by a model averaging procedure were applied on weed metrics and permutational multivariate analyses of variance were applied on weed species composition. Our analysis confirmed the overriding role of the distance to field margin on weeds. Although weed density and seed rain negatively responded to local management intensity, they did not respond in the same way to landscape configurational heterogeneity, namely the field size. We found interactions between management intensity and landscape heterogeneity but only in relation to weed biomass in beet and spring rape fields and to seed rain in beet fields. The relative importance of local management intensity and landscape heterogeneity varied depending on the distance to field margin, which can be attributed to spatial heterogeneity in management practices. We recommend that not only species richness but also a wide range of metrics should be considered in weed studies as they did not responded in the same way to local and landscape factors. We conclude that weed management strategies should be thought by integrating a multi-level approach as the combined effects of local management and landscape heterogeneity are likely to both reduce weed infestation whilst enhancing biodiversity.

1. Introduction

Managing agricultural pests while enhancing diverse communities that can support ecosystem services remains a challenging issue. Among the taxa found in agro-ecosystems, arable weeds are an interesting model. They play an important role in supporting biological diversity by providing food and shelter for a wide variety of farmland fauna (Marshall et al., 2003; Gibbons et al., 2006; Storkey, 2006; Bohan et al., 2007) such as invertebrates and birds. However, from an agronomic point of view, weeds represent a major problem for farmers because of the competition with the crop for available sunlight, water and nutrients (Bastiaans et al., 2000; Oerke, 2006) which could hinder crop productivity.

Weed response to environmental drivers, e.g. field management and landscape heterogeneity, have been investigated quite differently by agronomists and by ecologists (Hanzlik and Gerowitt, 2016). Agronomists have traditionally focused on quantifying the effects of in-field management (including weed control measures) on populations of problematic weeds (Walsh and Powles, 2014; Nkoa et al., 2015; Pannacci and Tei, 2014). Weed populations are described by their abundance or density, i.e. the measure of the number or frequency of individuals in an area, which reflects the current level of weed infestation in fields. Abundance may be also viewed as the outcome of both germination, seedling establishment and survival of weed species and thus, as an indicator of recruitment. Additionally, weed biomass, i.e. the measure of weed plants growth per unit area, can be used to quantify more finely weed response to agronomic practices and the competition with crop plants. Finally, in some instances, seed rain,

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i.e. the measure of seeds produced by a weed species and dispersed on the ground which can enter the soil seed bank, is used to assess how a population is likely to change over time and what levels of infestation might be found in the following crops (Hanzlik and Gerowitt, 2016; Nkoa et al., 2015). Because the ultimate goal of agronomists is to identify local weed management strategies, most agronomic studies have neglected factors acting at spatial scales larger than the field. However, specific management issues (herbicide resistance, GMOs gene flow, ragweed spread) currently drive agronomists to expand the spatial scale at which they work (Petit et al., 2013).

In contrast, ecological studies have commonly focused on identifying drivers that affect species richness and diversity in weed communities. There is a consensus today that both landscape heterogeneity and in-field management (such as herbicide application, nitrogen fertilization) explain some variation in weed richness patterns, although results have proved quite variable depending on the landscape context (for a review see Petit et al., 2013). At the field level, seed dispersal from fencerow vegetation to field centre have been proposed to create a mass effect onto certain crop types (Poggio et al., 2013). At larger levels, Henckel et al. (2015) suggest that seed fluxes, by generating mass effect and source-sink dynamics, allow weeds to persist locally in spite of landscape instability created by variations in farming systems. Such ecological dynamics influence species interactions, modifying colonization and extinction probabilities, within a network of local communities acting as a metacommunity (Leibold et al., 2004).

Surprisingly, weed density, biomass or seed rain have only rarely been considered although they represent quantitative measures of available resources for other taxa. A few landscape ecological studies have addressed variations in weed abundance or density, again with equivocal results (Hawes et al., 2010; Ekroos et al., 2010; Bohan and Haughton, 2012; Petit et al., 2016). Steffan-Dewenter et al. (2001) suggest that indirect mechanisms such as the contrasting responses of pollinators to landscape heterogeneity could affect pollination and, in turn, weed abundance. In the same way, landscape heterogeneity has been shown to affect the abundance of seed-eating predators and the amount of weed seed consumed in arable fields (Trichard et al., 2013; Petit et al., 2017) with potential impacts on the dynamics of individual weed species.

Previous research suggests that the effect of local management can be conditional on the landscape heterogeneity (Tscharntke et al., 2005; Concepción et al., 2008) while the effect of landscape heterogeneity could sometimes be detected only in specific farming systems (Weibull et al., 2003; Gabriel et al., 2010). In addition, recent advances in landscape ecology recognize two components of landscape heterogeneity: compositional and configurational heterogeneity. Compositional heterogeneity refers to the diversity of land cover types while configurational heterogeneity refers to their spatial arrangement (Fahrig et al., 2011). A clearer understanding of the relative effect of local management and landscape compositional and configurational heterogeneity on the full set of available weed metrics, and not only on species diversity, is needed. This is an essential prerequisite to develop weed management strategies that reconcile agronomical and ecological aims, i.e. reducing weed infestations whilst maintaining or enhancing weed biodiversity.

In this paper, we assess the relative effect of local management intensity and landscape heterogeneity on four weed metrics, replicated across 257 fields across Great Britain: species richness, density, biomass and seed rain. To our knowledge, this is the first study that evaluates the relationships between a set of four weed metrics and assesses their respective response to local management and landscape heterogeneity, alone or in interaction. As species are not homogeneously distributed within fields (José-María et al., 2010; Poggio et al., 2013), we examine how these relationships are modulated by the distance to field margin. We hypothesize that the effect of local management intensity should be higher in the centre of field and decrease towards the outer part of field. Although farming practices are aimed to provide spatially homogeneous and suitable conditions to produce high crop yields, spatial differences in the impact of management practices within field may persist (Poggio et al., 2013). Thus, we expect the distance to field margin to influence not only arable weed species richness, but also the prevalence of certain weed species more adapted to different disturbance levels. At larger level, the effect of the surrounding landscape should be higher near the field margin than in the centre of the field. As mentioned above, mass effect generated through dispersal of seeds from adjacent habitats as well as the corridor effect of uncultivated semi-natural habitats bordering fields, could explain such trends. We also hypothesize seed rain to be more contingent of landscape heterogeneity, i.e. the availability of semi-natural habitats in the surroundings of fields acting as weed refugia and/or seed sources, than on management intensity. In heterogeneous landscapes with small fields, short-range dispersal of seeds from adjacent semi-natural habitats would not be limited resulting in higher seed rain within fields compared to simpler landscapes with higher field size. Finally, and according to previous studies (Tscharntke et al., 2005; Concepción et al., 2008), we hypothesize that the effect of local management intensity on weed richness and density should depend on landscape heterogeneity.

2. Material and methods

2.1. Study area

Data come from the Farm-Scale Evaluations (FSE) of genetically modified, herbicide-tolerant (GMHT) crops (Champion et al., 2003; Heard et al., 2003). This study sampled the weeds in GMHT- and conventionally-managed halves of 66 spring-sown beet (B), 59 spring maize (M), 67 spring oilseed rape (SR) and 65 winter oilseed rape (WR) field sites. Each field was sampled once (Firbank et al., 2003a), and the experiment ran between 2000 and 2004 with about one-third of the fields being randomly sampled per year. In some cases, multiple fields in the FSE could come from the same farm and be managed by the same farmer. However, these cases were limited to one field per farmer per year and the same field was never re-used. Detail statistical analysis of the power of the FSE data-set for detecting change in farmland communities has demonstrated that these fields can be treated as replicates (Clark et al., 2006, 2007).

The fields were spread across four of the six Environmental Zones of the Institute of Terrestrial Ecology (ITE) Land Classification of Great Britain (Firbank et al., 2003b) that describe the environmental and geographical properties of each field (Fig. 1). The distribution of fields among the four zones was uneven. Most fields came from Zone 1 (southerly and easterly lowlands of England and Wales, N = 137 fields), Zone 2 (northerly and westerly lowlands of England and Wales N = 102 fields), and Zone 4 (lowlands of Scotland, N = 16 fields) with relatively few sites being represented in Zone 3 (uplands of England and Wales, N = 2 fields). Fields ranged in size from 2.7 to 70.8 ha, with an average of 11 ha, 79.4% of which were assessed to have hedgerows. Other field borders that were observed included footpaths and tracks, fences, ditches, ponds and streams, walls and urban areas. Only data from the conventionally-managed treatments were used for the analyses presented in this study, with all data from GMHT treatments being removed. Herbicide management in the conventional treatment followed normal farm management practice designed to achieve "cost-effective weed control" (Champion et al., 2003). No stipulation of the types of herbicides used was made for the conventionally-managed treatments.

2.2. Weed data

Weed individuals were counted in quadrats of 0.25 m × 0.5 m located at 2 and 32 m from the field margin along 12 transects (Fig. A.1 in Supplementary material). Where densities were very high (more than 100 individuals per quadrat), counts were made for these species