Scale-depend effectiveness of on-field vs. off-field agri-environmental measures for biodiversity

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Abstract

Measuring the effectiveness of agri-environment schemes depends on scheme type, taxon and landscape. Here we show how spatial scale, i.e. studied transect, field or farm level, and controlling for yield loss, can drastically change the evaluation of biodiversity benefits of on-field (organic farming) vs. off-field (flower strips) schemes. Transects may lead to misleading evaluations, because flower strips, covering only 5% of conventional fields, support less bees than large organic fields; but if their 20% yield loss is considered to compare identical yield levels, 80 ha conventional plus 20 ha flower strip farming promotes more bees than 100 ha organic farming.

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Abstract

Measuring the effectiveness of agri-environment schemes depends on scheme type, taxon and landscape. Here we show how spatial scale, i.e. studied transect, field or farm level, and controlling for yield loss, can drastically change the evaluation of biodiversity benefits of on-field (organic farming) vs. off-field (flower strips) schemes. Transects may lead to misleading evaluations, because flower strips, covering only 5% of conventional fields, support less bees than large organic fields; but if their 20% yield loss is considered to compare identical yield levels, 80 ha conventional plus 20 ha flower strip farming promotes more bees than 100 ha organic farming.

There is a decades-long discussion on how landscape may be designed delivering high agricultural productivity and biodiversity conservation alike (Zhang *et al.* 2007; Landis 2017). To address these challenges, a variety of agri-environment schemes (AES) have been introduced (Batáry *et al.* 2015). The AES exhibit a positive effect on species richness and abundance of farmland biota, but these effects depend on taxonomic group, landscape structure and ecological contrast between the treated and the control site (Batáry *et al.*2015; Marja *et al.* 2019). Recently, (Batáry *et al.* 2015) reviewed the broad range of European AES with a meta-analysis and compared their relative contributions to biodiversity conservation. AES approaches can focus on non-productive areas, such as field boundaries and wildflower strips (off-field practices (Garibaldi *et al.*2014)), or productive areas, such as arable crops or grasslands (on-field practices). Schemes promoting off-field areas include hedgerows (often for bird conservation (Batáry *et al.* 2012)), sown or naturally regenerated field margins (often flower strips for pollinators (Pywell *et al.* 2012)) or simply taking land out of production (e.g. abandoned land for great bustard conservation in Hungary (Kovács-Hostyánszki *et al.* 2011)). In contrast, on-field practices support environmentally sensitive approaches to the management of land that is used to grow crops or feed livestock. For example, they might reduce or prohibit the use of agrochemicals or confine management such as mowing grassland within specified points in time. The most widespread on-field scheme is organic farming (Reganold & Wachter 2016; Seufert & Ramankutty 2017). Batáry *et al.* (2015a) found that off-field schemes were much more effective at enhancing species richness than on-field schemes. The conversion of crop monocultures to semi-natural habitat results in a much larger increase in resource availability (i.e. creates a larger ecological contrast to the untreated control) for a wider range of species than on-field schemes, such as reducing stocking rates or restricting fertilizer and pesticide application in organic farming (Marja *et al.* 2019). Furthermore, schemes promoting the establishment of wildflower strips might be better targeted to the conservation of a given species group than on-field schemes, because they often specifically address a resource that is limiting population growth or size, e.g. floral resources for flower visiting insects (Warzecha *et al.* 2018).

However, the meta-analysis by Batáry *et al.* (2015a) has limitations in the comparison of off- vs. on-field practices, as it combines very different studies, which refer to biodiversity gains at very different spatial scales. For example, insect and plant surveys cover typically only a minor part of a study field (e.g. the field margin) without considering upscaling the effect size to the whole field or farm. Further, biodiversity-yield trade-offs have not been considered. Gabriel *et al.* (2013) showed in a large scale UK study that arthropod diversity did not differ between organic and conventional cereal fields when controlling for the more than 50% yield loss in organic farming. Here, we focus on different spatial scales of two most popular AESs (Batáry *et al.* 2015), namely organic farming as on-field measure and planted flower strips as off-field measure, leading to contrasting assessments of their biodiversity value.

In general, organic farming is applied at farm scale, and organic farmers do not apply for flowering strip (FS) schemes. Hence, FS as an AES is typically used by conventional farmers. FS are usually sown with seed mixtures of wild flowers and/or flowering crop species on arable land along field boundaries (Marshall & Moonen 2002; Warzecha *et al.* 2018). The width, the species mixtures and the management of the strips vary between countries and even between states. FS are most often targeted for insect conservation, especially favouring flower visitors to ensure crop pollination and natural enemies contributing to biological pest control (Wratten *et al.* 2012; Blaauw & Isaacs 2014; Tschumi *et al.* 2015). Haaland *et al.* (2011) found in their review that sown wild FS support higher insect abundances and diversity than cropped habitats.

In this study, we illustrate four different scenarios of scale-dependency of these agri-environment schemes by using wild bee data of three types of surveys (organic wheat field, conventional wheat field and conventional wheat fields with FS) from ten landscapes replicated in two years (methods: Supplement 1). We investigated, whether the effectiveness of the two AES (relative to the control, i.e. conventional fields) depends on the spatial scale considered. We supposed that scaling up the transect level data to field or farm level, by considering their larger contribution due to their larger area, and controlling for yield loss, might significantly change the whole picture.

Tuck *et al.* (2014) found in their meta-analysis that organic management supports 30% higher species richness per 1 ha field than conventional management. Flower strips adjacent to conventional fields are often found to be even more species rich than organic fields without such strips. Batáry *et al.* (2015) quantified this in their meta-analysis in that off-field practices (often flower strips) were more effective measures in maintaining or restoring biodiversity than measures on productive areas, such as organic farming on arable land or grassland; effect size of off-field practices was about two times high than that of on-field practices. In this scenario, comparisons consider the transect level, i.e. sampling of pollinator data at the transect level of organic vs. conventional vs. FS (adjacent to conventional fields) (Geppert *et al.* 2020), exhibiting an eight times higher effectiveness of FS than organic management (Fig. 1a).

The second scenario focuses on the field level, considering the area share of sown flowers in case of FS fields (Fig. 1b). When FS occupy 15% of a conventional field, which was the situation in our study (Geppert *et al.* 2020), the effectiveness of conventional management with FS was still 43% higher than the effectiveness of organic management (compared to conventional fields without FS). Hence, the difference at field level is much less expressed than in the transect scenario.

In the third scenario, we further scaled up pollinator abundance data to farm level with farm size of 100 ha. In case of conventional farming with FS, this extrapolation of field to a 100 ha farm level considered 5% area taken out for FS. We took 5% FS, as it corresponds to the minimum area of the greening measure of the Common Agricultural Policy (Zinngrebe *et al.* 2017). We found that 100 ha organic farming, which is usually characterized by a much higher cover of flowering weeds than conventional fields (Batáry *et al.* 2013), was about twice more effective than 100 ha conventional farming including FS in supporting pollinator abundance. This is because organic management promotes bee abundance with a 20 times larger area than the small area (5 ha) of flower strips. Holzschuh *et al.* (2008) showed that increasing the area with organic farms per landscape from 5% to 50% triples the number of bee species on surrounding fallows.

The last scenario controls for yield loss in organic compared to conventional farming (Gabriel *et al.* 2013). As productivity of organic farms is, on average, 20% lower worldwide (Seufert & Ramankutty 2017), 100 ha organically managed farm may be compared with 80 ha conventional farm with 20 ha flower strips, thereby producing equal crop yield. In this situation, the same yield per 100 ha farm is the target, and we found that organic farming supported about 40% fewer pollinators due to the large area of flowering strips/fields allowed in conventional farming. When organic yield is even halved (as in case of cereals (Gabriel *et al.* 2013; Batáry *et al.* 2017)), the difference can be even much higher. Finally, one might consider further scenarios that we could not test with our data. For example, if organic farmers manage their farms with higher crop diversity and longer crop rotations than conventional farmers, biodiversity might further increase (Sirami *et al.* 2019).

A plethora of studies addresses the ecological effectiveness of different agri-environment schemes with nearly all of them focusing exclusively on the transect level (Batáry *et al.* 2015), whereas upscaling to higher spatial scale (field or farm level) is rare (Batáry*et al.* 2017). Although small-scale off-field measure can have a very positive biodiversity outcome at that scale, such as in case of flower strips, upscaling to field and farm level can reveal that the biodiversity benefit of FS is on par or even lower than that of on-field measures such as organic farming (Geppert *et al.* 2020). Focusing studies on the transect scale can give misleading results, as FS make up typically only ca. 5% of a conventional farm, enhancing less bees than a same sized organic farm. This, can be turned around again, when we control for yield losses from organic farming (Chave 2013). As yield in organic farming is on average 20% lower, 100 ha organic farm has the same productivity as 80 ha conventional farm with 20 ha flower strips, which supports much higher biodiversity than organic farming. In conclusion, considering various scales in the evaluation of AES measures is necessary in order to get a balanced understanding of their ecological and also economic effects for further development of their effectiveness.

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Figure 1. Bee abundance sampled at transect level in organic field, conventional control field and flower strip, and their upscaling to field and farm scales with different scenarios. Scenario 1: At transect level, the effectiveness of flower strip (FS) scheme (EF2: compared to conventional field) was eight times higher than the effectiveness of organic management (EF1: compared to conventional field). Scenario 2: At field level, when FSs occupied 15% of a conventional field, the effectiveness of conventional management with FS (EF3) was 43% higher than the effectiveness of organic management (EF4). Scenario 3: Based on the same farm area (100 ha), organic farming was more effective (EF5) than conventional farming containing 5% FS and 95% conventional fields (EF6). Scenario 4: Based on the same farm area (100 ha) and same yield loss, i.e. conventional farming with ca. 20% FS (EF8) was more efficient than organic farming (EF7) (n = 60 transects and fields; n = 40 farms). Error bars represent standard error of mean. Significance levels: ***P < 0.001. Abundance closely correlated with species numbers in our dataset (Pearson's r = 0.80, P < 0.001).