Agriculture, Ecosystems and Environment 246 (2017) 109–116

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

# Landscape effects on pollinator communities and pollination services in small-holder agroecosystems

Yi Zou[a,1], Felix J.J.A. Bianchi[b], Frank Jauker[c], Haijun Xiao[d,*], Junhui Chen[d], James Cresswell[e], Shudong Luo[f], Jikun Huang[g,h], Xiangzheng Deng[h], Lingling Hou[g,h], Wopke van der Werf[a]

[a] Centre for Crop Systems Analysis, Wageningen University, Wageningen, The Netherlands
[b] Farming Systems Ecology, Wageningen University, Wageningen, The Netherlands
[c] Department of Animal Ecology, Justus Liebig University, Heinrich-Buff-Ring, Giessen, Germany
[d] Institute of Entomology, Jiangxi Agricultural University, Nanchang, China
[e] Biosciences, University of Exeter, Exeter, UK
[f] Institute of Apicultural Research, Chinese Academy of Agricultural Sciences, Beijing, China
[g] School of Advanced Agricultural Sciences, Peking University, Beijing, China
[h] Centre for Chinese Agricultural Policy, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, China

ARTICLE INFO

*Keywords:*
Arable land
Biodiversity
Canola
Ecosystem service
Yield
Wild bee

ABSTRACT

Pollination by insects is key for the productivity of many fruit and non-graminous seed crops, but little is known about the response of pollinators to landscapes dominated by small-holder agriculture. Here we assess the relationships between landscape context, pollinator communities (density and diversity) and pollination of oilseed rape in 18 landscapes with proportions of small-holder farming ranging from 10% to 70% in southern China. To quantify the contribution of pollinators to oilseed rape yield, we manipulated pollinator access in a focal oilseed rape field in each landscape using open and closed cages. The pollinator communities in the focal fields were sampled using pan traps. The abundance of wild pollinators increased significantly with the proportion of cultivated land, but the diversity of the wild pollinator communities declined. The responses of pollinator abundance and diversity to cultivated land were best explained at scales of around 1000 m. The abundance of the unmanaged honey bee *Apis cerana* was positively associated with the proportion of cultivated land, whereas the abundance of the managed *A. mellifera* was not. A pollination services index (PSI) was calculated by comparing the reproductive investment in seeds between plants with or without pollinator access. PSI was positively correlated with wild pollinator abundance, but not with the abundance of honeybee species. PSI was also not significantly correlated with the area proportion of cultivated land. Our results indicate that crop dominated landscapes with numerous small fields supported an abundant, but relatively species poor bee community that delivered pollination services to oilseed rape. Conservation of (semi-)natural habitats, however, is important for maintaining the diversity of wild pollinators.

## 1. Introduction

Pollination by insects is an important ecosystem service for a variety of crops (Klein et al., 2007; Ollerton et al., 2011) and is associated with landscape factors that benefit pollinators (Kremen et al., 2007; Potts et al., 2010; Batary et al., 2011; Bommarco et al., 2012; Hadley and Betts, 2012; Kennedy et al., 2013; Scheper et al., 2015; Baude et al., 2016). Semi-natural habitat has been positively associated with wild bee abundance (Steffan-Dewenter et al., 2002; Öckinger and Smith, 2007) and diversity (Öckinger and Smith, 2007; Le Féon et al., 2010; Diekötter et al., 2014; Martins et al., 2015). The diversity of wild pollinators may also be influenced by the distance between forest and crops (Klein et al., 2003, 2003b), and their abundance may be boosted by the presence of mass-flowering crops (Westphal et al., 2003; Holzschuh et al., 2013; Diekötter et al., 2014; Riedinger et al., 2014). The relationships between (i) landscape context and pollinator community structure (abundance and diversity) (Steffan-Dewenter et al., 2002; Carré et al., 2009; Tscheulin et al., 2011; Bartomeus et al., 2014; Martins et al., 2015; Holzschuh et al., 2016), and (ii) the relationship between pollinator community structure and pollination service have been well established (Sabbahi et al., 2005; Jauker and Wolters, 2008; Bommarco et al., 2012; Garibaldi et al., 2013). However, we are not

* Corresponding author.
*E-mail address:* hjxiao@jxau.edu.cn (H. Xiao).
[1] Current address: Department of Environmental Science, Xi'an-Jiaotong Liverpool University, Suzhou, China.

http://dx.doi.org/10.1016/j.agee.2017.05.035
Received 27 January 2017; Received in revised form 17 May 2017; Accepted 29 May 2017
0167-8809/ 

aware of studies that report the full cascade from landscape context to pollinator community structure and yield. There is an urgent need to identify landscapes settings that support ecologically intensive production systems that are both productive and conserve biodiversity-based ecosystems services (Bommarco et al., 2013). This is not only true for intensive farming landscapes with large fields in developed countries, but it is equally relevant for farming landscapes dominated by small-holder agriculture in developing countries.

In contrast to North America and Europe, where intensive farming systems are characterized by large field sizes and monocultures of a limited number of crops, Chinese agroecosystems (especially in south China) have relatively small fields that may support a high diversity of crops and cultivars. These small-holder fields are often surrounded by small strips of non-crop habitats, potentially providing nesting habitats and floral resources for wild pollinators (Klein et al., 2003a; Kremen et al., 2007; Holzschuh et al., 2012), and are intricately interlaced in the landscape. A recent global study found that crop yield of small farms benefit more from pollination than large farms (Garibaldi et al., 2016). Managed honey bees have historically been considered a key crop pollinator, but recent studies showed that wild pollinators are also important for crop production (Winfree et al., 2008; Garibaldi et al., 2013; Lowenstein et al., 2015; Rader et al., 2016). Little is known about the relationship between landscape context and the diversity and abundance of pollinators in small-holder farming systems.

Here we studied pollination in oilseed rape (*Brassica napus* L.), which is a globally important crop for feed, cooking oil and biofuel. China is one of the largest producers of oilseed rape in the world (FAO, 2013), but pollination services in China are under pressure as exemplified by the need for hand-pollination of apples in the Sichuan province (Partap and Ya, 2012). Ironically, in highland regions of Sichuan and Chongqing, more than 20% of the world's approximately 250 bumblebee species have been recorded (Williams et al., 2009). Although oilseed rape is a self-pollinating plant species (Williams et al., 1986), it is also pollinated by insects and attracts a wide community of insect pollinators (Sabbahi et al., 2005; Jauker and Wolters, 2008; Bommarco et al., 2012; Stanley et al., 2013), which makes this crop suitable for studying generalist pollinators. Numerous studies on pollination have been conducted (e.g. Chifflet et al., 2011; Bommarco et al., 2012; Holzschuh et al., 2013; Lindström et al., 2016; Sutter and Albrecht, 2016), but none in small-holder landscapes.

The aim of this study is fourfold. First, we assess the relevant spatial scale for associations between the landscape context and pollinator abundance and diversity in small-holder farming landscapes. Second, we identify land-use types that influence pollinator abundance and diversity in oilseed rape fields. Third, we assess how pollinator abundance and diversity influence oilseed rape yield in these fields. Fourth, we establish whether pollination services can be directly linked to landscape context without considering pollinator abundance and diversity. As a null hypothesis, we expected the abundance and diversity of wild pollinators to decrease with the proportion of cultivated land and increase with the proportion of semi-natural habitat, while the abundance of managed honey bees was expected to be independent from landscape context because it is governed by the behaviour of bee keepers. We further expected that landscapes with more abundant and more diverse pollinator communities would receive more pollination services and therefore obtain higher oilseed rape yield.

## 2. Methods

### 2.1. Study area and land use survey

We selected a total of 18 focal oilseed rape fields in the broader region around the city of Nanchang, Jiangxi Province, China (N28.35°–N28.99°, E115.26°–E115.82°). The minimum distance between two focal fields was at least 5.8 km (Fig. 1), which exceeds the maximum foraging range for most bee species (Steffan-Dewenter et al., 2002; Chifflet et al., 2011). Fields had a mean size of 845 ± 86 $m^2$ (range 400–1400 $m^2$) and they were all sown with a single traditional oilseed rape bred cultivar (Yangguang 2009, semi-winter cabbage type oilseed rape) because pollination effects may differ among cultivars (Hudewenz et al., 2014; Lindström et al., 2016). During the study period, no pesticides were applied in the oilseed rape fields. Land use in the landscape surrounding the focal fields was quantified at a spatial scale of 2000 m radius and ground-truthed in July 2014 (2.5 m resolution). We assume the land-use data of 2014 to be representative for 2015 when measurements on pollinator community and oilseed rape yield were conducted. A total of 42 land-use types (Appendix A) were classified into seven categories: cultivated land (41.3 ± 4.8% (mean ± SEM throughout text), range 10.4%–69.8% at 2000 m radius), forest (38.2% ± 5.8%, range 10.4%–77.3%), grassland (7.2% ± 1.5%, range 0.5%–23.5%), orchards (1.1% ± 0.5%; range 0–7.6%), and three categories that were not used in the analysis (water, built-up areas and unused land, Fig. 1). There was a mismatch between the period of cultivation of oilseed rape (October–May) and ground-truthing (July). Therefore, oil seed rape was not represented in the ground-truthing analysis, and most likely overlapped with the land-use type 'middle rice' (Appendix A). Visual assessment of the crops around focal fields in February 2015 indicated that approximately one third of cultivated land contained oilseed rape (35% ± 5.6%, range 7%–81% at 100 m radius).

For the analysis, forest and grassland were pooled as semi-natural habitat. The proportion semi-natural habitat was not used in analysis because of a strong negative association with cultivated land (Pearson $R^2 = 0.95$, $P < 0.001$, Fig. 1). Because of this strong correlation, results for cultivated land would also apply (but with opposite sign) for semi-natural habitat. In order to still include the potential effect of forest, we added the distance from focal field to the nearest forest as an additional explanatory variable.

### 2.2. Pollinator sampling

Pollinator communities in the field were sampled with pan traps. In the centre of each focal field, four pan trap stations were set up at the corners of a 20 × 20 $m^2$ square. Each station consisted of a stake with three cups (8.3 cm diameter, 13.5 cm height and a volume of 450 ml) that were painted ultraviolet (UV) yellow, UV blue and UV white from the inside. Two 3 mm-diameter holes were drilled at 3 cm from the brim of the cup in order to drain excess rainwater. Cups were established at a height of 1.5 m. We used salt (NaCl)-saturated water with a few drops of detergent as killing agent. Sufficient liquid was added in the cup to avoid drying out. Traps were installed at the end of February 2015, before the onset of blooming, and removed after 49–52 days of exposure in the field, at harvest in mid-April 2015. The slight variation in sampling period was caused by differences between sites in the date of trap placement. No influence on the sampling is likely since traps were established before the activity period of most pollinators. We therefore consider that sampling effort among sites was practically identical. Cups were emptied and refilled five times, at approximately 10-day intervals. Pollinator samples of each site and sampling period were pooled, sorted, pinned and identified to species level when possible. No cup was lost, flooded or dried out.

### 2.3. Flower cover estimation

Oilseed rape flower cover was assessed by placing four quadrats of 0.5 $m^2$ randomly in the field and taking photos from above the canopy. Flower cover was estimated by exposing a 200 grid on top of the photo and counting the number of grids that contained oilseed rape flowers. Flower cover assessments were conducted at approximately 10-day intervals. The maximum flower cover for each focal field is referred to as 'peak flower cover', which was used as a proxy of the flower cover in the field. This "peak flower cover" was highly correlated with