Agriculture, Ecosystems and Environment 266 (2018) 142–152

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Tillage intensity or landscape features: What matters most for wild bee diversity in vineyards?

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A R T I C L E I N F O

Keywords:
Apiformes
Vineyard
Tillage
Landscape
Floral resources
Ecosystem services

A B S T R A C T

Vineyard inter-rows can provide habitats for a range of plant and animal species especially when covered with vegetation. However, frequent tillage results in the degradation of habitat quality and the provision of biodiversity-based ecosystem services. Wild bees are important pollinators of crops and wild plants and depend on both, floral resources and suitable nesting sites, which are influenced by the landscape configuration.

We examined effects of field and landscape parameters on wild bee species' richness, abundance and functional traits in Austrian vineyards over two years using Generalised Linear Mixed models, Detrended Correspondence Analysis and Random Forests. Alternating tillage was compared with no tillage in two inter-rows per vineyard. Forage availability in these inter-rows was estimated by flower coverage at each sampling date, and landscape features were analysed within a radius of 750 m around the vineyards.

Across all vineyards we found 84 wild bee species with a mean abundance (± SD) of 29 (± 16.6). Forage availability had the strongest positive effect on wild bee diversity and abundance. In comparison to no tillage, alternating tillage slightly increased wild bee diversity and abundance. Eusocial wild bees were more abundant in untilled inter-rows, whereas solitary wild bees were more closely associated with alternating tilled vineyards. At the landscape scale, the percentage of artificial areas (mostly villages) and distance to semi-natural elements raised wild bee diversity and abundance. The proportion of woodland increased the abundance of wild bees, in particular of eusocial taxa. Solitary wild bee abundance was enhanced by the number of solitary trees.

Pollination provided by wild bees in viticultural areas can be enhanced by maintaining a diversity of different soil management strategies to improve forage availability in vineyards. Furthermore, semi-natural elements such as fallows or solitary trees providing floral resources and nesting habitat should be preserved within viticultural landscapes.

1. Introduction

In agroecosystems, a large proportion of pollination services are provided by wild bees (Klein et al., 2007). The monetary value of insect pollination to agriculture was estimated at about 150 billion Euro worldwide (Gallai et al., 2009). Intensive agriculture is deteriorating habitat quality at different spatial scales (Kennedy et al., 2013) by increasing local disturbance and reducing landscape complexity. Parallel decrease of pollinators and insect-pollinated plants were observed in two european countries (Biesmeijer et al., 2006).

Pollination performance (quantity and quality of fruit set and yield) of certain crops has been linked to wild bee species richness (Holzschuh et al., 2012; Klein et al., 2003; Mallinger and Gratton, 2015) and to functional diversity (Fontaine et al., 2006; Garibaldi et al., 2015). Because of certain adaptations, like the activity of bumble bees at relatively low temperatures or oligolectic foraging behaviour, wild bees can

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https://doi.org/10.1016/j.agee.2018.07.018
Received 2 November 2017; Received in revised form 14 July 2018; Accepted 24 July 2018

be more efficient in pollinating wild plants or crops compared to honey bees (e.g. Mallinger and Gratton, 2015, reviewed in Klein et al., 2007). There is a consensus about the complementary pollination efficiency of wild and honey bees (Brittain et al., 2013; Greenleaf and Kremen, 2006; Isaacs et al., 2017).

Wild bees are central place foragers, depending on floral resources (pollen and nectar) and suitable nesting sites (e.g. sparsely vegetated ground, stems, dead wood, cavities) within species-specific flying distances (Westrich, 1989a). Wild bee diversity has been shown to be affected by farming practices and landscape composition (Andersson et al., 2013; Kleijn and van Langevelde, 2006), and is closely related to the proportion and distance of semi-natural elements (SNE) (Le Féon et al., 2013; Morandin and Kremen, 2013). In viticultural areas, fallows, hedgerows, natural grasslands, solitary (fruit) trees as well as stone and loess walls may be beneficial SNEs for wild bees. These elements can provide nesting habitats and floral resources for wild bees and, over a larger spatial scale, enhance pollination in intensively managed farmland (Albrecht et al., 2007). Thus, pollination services are altered by management practices on the field and landscape scale (Connelly et al., 2015; Cusser et al., 2016; and reviewed in Kennedy et al., 2013).

The cultivation of vine dates back to the Mesolithic Age and originated in the Caspian Sea region and later spread from Greece to Middle Europe (Bauer et al., 2013). Today, vineyards cover about 7.6 million hectares worldwide (OIV, 2018). Vineyards are restricted to climate types of comparatively dry and warm/hot summers which also support several thermophilic species. Vine (*Vitis vinifera* L.) is mainly self-pollinated, insect and wind pollination play a minor role for grape yield (Cabello Saenz et al., 1994). Although observations exist of honey bees foraging on vine, the plant flowers a relatively short time, thus offers very limited pollen resources and no nectar for bees (Vorwohl, 1977).

Winegrowers manage potential water and nutrient competition between inter-row vegetation and vines by tilling, mulching or through the application of herbicides (Pardini et al., 2002). At low management intensity, the inter-row space between the vines is covered with spontaneous vegetation or cover crops, which can provide floral resources for wild bees and nesting habitats especially for ground-nesting species. It has been shown that strategies to support pollinators enhances overall biodiversity and associated ecosystem services like biological pest control, soil and water protection, and soil erosion (Wratten et al., 2012). So far, no significant effect of organic versus conventional vineyard management or natural habitats in the surrounding landscape on wild bee species richness and abundance has been reported (Kehinde and Samways, 2014a, 2014b, 2012). Knowledge about how soil tillage affects wild bees is scarce compared to other management parameters (Ullmann et al., 2016; Williams et al., 2010). A meta-analysis revealed a knowledge gap of how pollinators respond to management intensity (i.e. tillage frequencies) in vineyards (Winter et al., 2018).

This study investigates the effects of field (soil tillage, forage availability) and landscape parameters on wild bee species' richness, abundance and traits in vineyards and discusses the consequences for pollination services in viticultural landscapes. The objectives were (i) to evaluate the most important field and landscape parameters and how they affect wild bee richness and abundance in vineyards, and (ii) to analyse how wild bee traits and representative species interact with field and landscape parameters.

2. Methods

2.1. Study sites

The study sites were located in two Eastern Austrian viticultural areas (Fig. 1), in Carnuntum (48° 04′ N, 16° 47′ E, province of Lower Austria) and Neusiedlersee-Hügelland (47° 54′ N, 16° 41′ E, province of Burgenland). The rainfed vineyards are spread over the small to medium scaled agricultural landscape and consist of small parcels (0.4–1.0 ha) with trellis systems on plain or hilly terrain. Besides vineyards, arable fields and other landscape features, like SNE, woods or villages, characterize the landscape. The climate is continental. In 2015 the average temperature was 11.5 °C and annual precipitation was 508 mm, while in 2016 the average temperature was lower (11.1 °C) and the annual precipitation was 636 mm (ZAMG, 2017).

We selected a total of 16 vineyards, each embedded in a landscape circle of a 750 m radius and investigated each vineyard during two consecutive years (2015 and 2016). The 750 m radius was chosen to ascertain a minimum distance of 1500 m between the studied vineyards which covers the foraging distance of different wild bee species (Zurbuchen et al., 2010). The vineyards ranged in age from 6 to 58 years (years of establishment until 2016). The cultivated vines comprised different red (Zweigelt, Blue Frankish, Blue Portuguese) and white varieties (Grüner Veltliner, Welschriesling, White Burgundy, Chardonnay, Muscatel). The studied vineyards differed in the applied inter-row tillage regime: No tillage, when the last tillage event was performed five or more years ago and resulted in permanent vegetation cover. Alternating tillage was defined as tillage in every second inter-row one to three times annually and resulted in temporal vegetation cover. In 2015, eight vineyards were untilled and eight were alternatingly tilled. In 2016 one untilled vineyard was surprisingly tilled in early spring and therefore was excluded from analysis. We decided to include an alternatingly tilled, neighbouring vineyard in the analysis for 2016 instead, which was also subject of soil and plant investigations in the same project (Fig. 1).

2.2. Sampling procedure

Wild bees were sampled with a semi-quantitative standard transect method by establishing 200 m^2 transects along inter-rows. The length of each transect was adapted to the width of the respective inter-row which ranged between 1.5 and 2 m across the studied vineyards. To detect possible effects of alternating tillage, each transect was split up into two parts: one 100 m^2 transect was established in the vegetated inter-row, the other in the neighbouring inter-row with soil tillage. Sampling dates were adjusted to the vine's phenology because the phenological stages (first leave buds, first flower buds, full florescence, berries have pea size and begin of maturation; Bauer et al., 2013) comply with wild bee sampling recommendations which should be conducted monthly from April to September (Schindler et al., 2013). This resulted in five transect walks in every vineyard between April (first leave buds) and August (begin of maturation of grapes) in both study years. Each sampling campaign was done within 2–3 days with sunny and nearly windless weather conditions and temperatures above 15 °C. Except for bumble bees (*Bombus*) and honey bees (*Apis mellifera*), which were identified and counted in the field, all other wild bee individuals were collected during a 15 min transect walk using a sweep-net, and identified to species level in the lab (Amiet, 1996; Amiet et al., 2010, 2007, 2004, 2001, 1999; Gokcezade et al., 2010; Mauss, 1994; Scheuchl, 2006, 2000; Schmid-Egger and Scheuchl, 1997), using the nomenclature according to Gusenleitner et al. (2012). Further, nests from ground-nesting wild bees were documented qualitatively if such observations occurred during sampling. Floral resources in the inter-rows (as a proxy for forage availability) were recorded at each sampling date along each transect. The flower coverage of all momentarily flowering entomophilous plants was visually estimated on each sampling event in five classes (< 1% = very low; 1–5 % = low; 5–25 % = medium; 25–50 % = high; 50–100 % = very high) following an adapted DAFOUR scale (Gardener, 2012). Similarly, the number of those entomophilous flowering plant species was documented.

Bees' functional traits (Table 1) and their relation to pollination efficiency and fruit set (De Palma et al., 2015; Fontaine et al., 2006; Garibaldi et al., 2015) were obtained from a literature search (Greenleaf et al., 2007; Scheuchl and Willner, 2016; Westrich, 1989b). To estimate the activity range of species we measured the inter-tegular-distance (ITD) of 1–5 individuals per species according to Cane (1987)