Effects of mass flowering crops on wild pollinator abundance and species richness

– A review of local and landscape effects in the agricultural landscape

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Abstract

Agricultural intensification has led to the loss of flowering resources and natural habitats in agricultural landscapes and has been identified as one of the major drivers for the observed decline in wild pollinators in these habitats. It has been suggested that mass flowering crops could be used to counterbalance this negative trend. However, the presence of mass flowering crops is not always beneficial to wild pollinators. This thesis presents a review of the published literature on the effects of mass flowering crops on wild pollinator abundances and species richness and aims to explore the reasons for variation in the observed effects. I found 12 papers that looked at the impact of mass flowering crops on either wild pollinator abundances or species richness in natural habitats. The 12 papers yielded a total of 37 studies: 7 studies on pollinator species richness and 30 studies of wild pollinator abundances. 6 out 7 studies showed negative effects on pollinator species richness. Out of the 30 studies on wild pollinator abundances, 8 studies showed a positive effect of mass flowering crops on wild pollinator abundances, and 18 showed a negative effect. Generally, mass flowering crops had a negative effect on pollinator species richness, possibly due to mass flowering crops benefitting only a few generalist pollinator species. On the other hand, the presence of mass flowering crops appeared to be beneficial for wild pollinator abundances, especially at the local scale. Mass flowering crops seemed to promote positive spill-over of pollinators into the adjacent semi-natural habitats. However, at the landscape scale, when landscapes with and without mass flowering crops were compared, the effect of mass flowering crops was less clear. The effect of mass flowering crops seemed to vary depending on crop type and flowering time. Therefore, I conclude that more research is needed to identify the conditions under which mass flowering crops are beneficial for wild pollinator abundances and species richness.

Keywords: Mass flowering crops, wild pollinators, species richness, spill-over, dilution

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Abbreviations

MFC	Mass flowering crop
SNH	Semi-natural habitat
OSR	Oilseed rape

1. Introduction and purpose

1.1. Introduction

Over the last century the agricultural landscape has changed dramatically due to increased food demand and farming intensification. Innovations and practices such as mechanisation, increased use of fertilisers and pesticides has exacerbated this intensification, as a result, wild floral resources have decreased in agroecosystems (Robinson & Sutherland 2002). The loss of semi-natural habitats (SNHs) and flower resources has had negative implications for a variety of species living in the agricultural landscape, leading to a decline in species abundances as well as diversity (Hanley *et al.* 2011). An important group that is affected by agricultural intensification is wild pollinators, a group that is in decline partly due to loss of flowering resources and natural habitats for nesting (Potts *et al.* 2010; Bommarco *et al.* 2012).

Wild insect pollinators are an important group as they provide an essential ecosystem service by pollinating crops. Simultaneously, flowering crops provide pollinators with pollen and nectar. Pollination can increase the yield of crops and it has been estimated that 39 of 57 leading crops worldwide increase in yield as a result of insect pollination (Klein *et al.* 2007). It has been suggested that flowering crops can be used to counterbalance the loss of wild flowers in agricultural landscapes (Schellhorn *et al.* 2015). For example, mass flowering crops (MFCs), such as oilseed rape *(Brassica napus)*, have been shown to increase bumblebee densities at the landscape scale (Westphal *et al.* 2003). With the addition of nearby nesting sites, cultivation of oilseed rape has to potential to increase the abundance of solitary bees (Holzschuh *et al.* 2013). However, MFCs do not always have positive effects on wild pollinators. Westphal et al. (2009) showed that oilseed rape had a positive effect on bumblebee worker abundance early in this season, but that this did not translate into a positive effect on bumblebee reproduction later in the season. This is because MFCs provide a spatially and temporarily limited resource (Tscharntke *et al.* 2012; Schellhorn *et al.* 2015). Therefore, MFCs may not always benefit wild pollinators.

The effect that MFCs have on pollinator abundances and species richness is a subject that has been researched since the early 2000s (Westphal *et al.* 2003). The subject is relevant because the interaction between crops and pollinators has economical value as yield of many MFCs increases with insect pollination (Klein *et al.* 2007). Also the subject of how MFCs interact with wild pollinators is relevant from an agricultural perspective, because it tries to answer the question of how the landscape is best managed to maximise insect pollination (Potts *et al.* 2010; Schellhorn *et al.* 2015). Investigating the effect of MFCs on wild pollinators has both economic and conservational value, which makes it worth studying.

This thesis investigates the effects of MFCs on wild pollinators in agricultural landscapes, by recording pollinator abundances and species richness from published studies across a range of MFCs. More specifically, I will investigate whether the type of mass flowering crop, the spatial scale of the study (i.e. local or landscape scale) and the type of study design (i.e. an experimental study design or a study design that measured wild pollinator abundances and species richness over an increasing coverage of MFCs, hereafter called "gradient") impacts the effect of MFCs on wild pollinator abundances and species richness. The results will be discussed using two major ecological theories: the "dilution effect" and the "spill-over effect". Comparing published data on wild pollinator abundances and species richness can give us new knowledge on the overall impacts of MFCs. I have also presented the years the papers were published and in which countries they were conducted in order to give an idea of how long the subject has been researched for and where the effects are measured.

1.2. Purpose

The purpose of this thesis is to research the effects of MFCs on wild pollinators and to test the hypothesis that MFCs generally have a positive effect on pollinator abundances and species richness. This will be done by looking at three specific variables that could affect pollinator abundances and species richness.

Firstly, I will investigate if there are differences in pollinator abundances and species richness depending on the crop type, specifically if there are differences between early mass flowering crops and late mass flowering crops. Secondly, I will test whether the effect of MFCs on pollinator abundances and species richness varies with the scale used in the study. Studies can be categorized as either a "local" or "landscape" scale study: the "local" scale studies are done at the "edge" of MFC fields i.e. field margins, "landscape" studies are measured over a larger area (1 to 3 km radii). Lastly, the studies reviewed used either experimental or gradient designs, and the aim of this study is to test if there are different effects on wild pollinator abundances and species richness depending on the study design. Experimental studies were studies done with and without a MFC: the without being the control. Gradient studies were done with relative high/low coverage of MFCs in a landscape, the low relative coverage used as a control site.

2. Background

2.1. Crop Phenology

MFCs flower at different times during the season. This will determine when they are an available resource for pollinators. Table 1 shows the flowering time of the crops in the reviewed studies. In Europe the area used to cultivate MFCs has increased, but it is mostly early flowering crops such as oilseed rape ("European Commission, Agridata" 2020). Late flowering crops, such as sunflower (*Helianthus annuus*), red clover (*Trifolium pratense)* and faba bean (*Vicia faba*) have also increased in coverage but not to same extent as oilseed rape ("European Commission, Agridata" 2020). In addition, the area over which early mass flowering crops is cultivated is greater than the area that late mass flowering crops is cultivated over ("European Commission, Agridata" 2020).

Table 1. Phenology and peak flowering time of the crops investigated in the reviewed studies.

Crop	Phenology	Peak flowering period	Reference
OSR, *Brassica napus*	Early	April -June	Magrach et al., 2018
Orange, *Citrus x sinensis*	Early	Unreported	Holzschuh et al., 2016, Jung & Müller 2009
Hedysarum, *Hedysarum coronarium*	Early	April-May	Montero-Castaño et al., 2016
Strawberries, *Fragaria x ananassa*	Early	May-June	Ganser et al., 2018
Sunflower, *Helianthus annuus*	Late	August	Todd et al., 2016

Faba beans, *Vicia faba*	Late	June	Hanley et al., 2011
Red clover, *Trifolium pratense*	Late	June-July	Rundlöf et al., 2014

The variation in flowering time of MFCs affects pollinator abundances and species richness throughout the season. Schellhorn et al. (2015) presented the idea of bottlenecks in managed landscapes: when there are not sufficient food resources during a period for an organisms' lifecycle, its survival rate and population size decreases. For wild pollinators this has been shown to be the case for bumblebees. Early MFCs i.e. oilseed rape has been shown to increase the number of workers at the beginning of the season, but this does not translate into higher reproductive success i.e. the production of queens and males later in the season (Westphal *et al.* 2009). However, when a late flowering MFC is added to the landscape i.e. red clover it increases the production of queens and males (Rundlöf *et al.* 2014). This shows that a landscape with a consistent flowering of crops will likely be more positive for pollinator abundances and richness. It also highlights that crop phenology can affect pollinator abundances and richness: where early flowering crops promote abundance of workers and late flowering crops promote abundance of queens and males.

2.2. Pollinators

This study has mainly dealt with different bee species because they were the most common pollinator type that the reviewed studies investigated. However, for species richness other types of pollinators were measured most reviewed studies included bees and hoverflies (Le Féon *et al.* 2013; Montero-Castaño *et al.* 2016; Magrach *et al.* 2018). Bees can be managed or wild. If bees are managed their abundance will mainly be driven by anthropogenic factors and not by the presence of MFCs. Honeybees are the classical example of a managed pollinator (however not all honeybees are managed) and farmers often keep hives near flowering crops to increase yield (Klein *et al.* 2007). Since honeybees are brought to the crop rather than occur naturally, the abundance of honeybees from the reviewed studies was separated, where possible, from wild pollinator abundance (Appendix 3), as wild pollinators will respond to changes in the landscape.

Pollinators belong to different functional groups and can be either generalists or specialists in respect to the flowers they pollinate. Generalist pollinators include honeybees, or short tongued bumblebees, specialists include long tongued bumblebees (Goulson *et al.* 2005). Goulson et al. (2005) determined that generalist pollinators occur in greater abundances than specialists. Specialists were generally found in smaller numbers because they required diverse flowering resources that were less available (Goulson *et al.* 2005). It has also been shown that a greater diversity of flowers can benefit both abundance and species richness of wild pollinators (Hülsmann *et al.* 2015). MFCs are composed of a single species of flower and will therefore not benefit all pollinator species.

2.3. Importance of spatial scales

When investigating the effect on MFCs on pollinators it is important to determine the spatial scale of the study. The reviewed studies were either conducted at local or landscape scale. Local scale studies are studies where measurements of pollinator abundances and species richness was done at the edge of MFC fields. In landscape scale studies the measurements were done over a greater area. Comparing these approaches can tell us if there is a difference in abundances or species richness depending on scales. Therefore, the studies reviewed were categorised as either local or landscape scale studies.

2.3.1. Local scale: Edge

Edges are the field margins and are often richer in flower diversity than the neighbouring crop field. Edges can constitute the main source of flower and nesting habitat for certain species in agricultural landscapes as they are relatively undisturbed (Gilbert *et al.* 1998). The effect of MFCs on pollinators can be studied at the local edge-crop field scale. For example, local scale effects of MFCs have generally been investigated by comparing pollinator abundances and species richness at the edge of a MFC and at the edge of a non-flowering crop (i.e. cereals). Mendoza-García et al. (2018) conducted a study where the comparison was made in field margins of cereals and oilseed rape. The study sites for the MFC was in the field margins between to fields: oilseed rape – cereal and the control was field margins between cereal – cereal fields (Mendoza-García *et al.* 2018).

2.3.2. Landscape scales

Pollinators (especially bees) can forage over large distances. Honeybees and bumblebees can forage for distances up to 10 km from their nest and regularly forage up to 3 km (Osborne *et al.* 1999; Steffan-Dewenter *et al.* 2002). Ultimately, the foraging distance depends on the amount of floral resources available in the area and pollinators will not fly longer distances than necessary to collect nectar and pollen (Osborne *et al.* 1999; Steffan-Dewenter *et al.* 2002). Depending on the landscape, larger areas can hold a greater diversity of habitats than smaller areas and if the habitats are diverse the species richness is expected to be greater than in a simple landscape with a single land use (Tscharntke *et al.* 2012). Additionally, a simplified landscape with high connectivity of SNHs can hold a greater abundance and species richness than the same sized area without connected semi-natural patches (Tscharntke *et al.* 2012). Some studies investigating the effect of MFC have done landscape scale studies over larger areas, comparing landscapes with and without mass flowering crops.

The studies that were conducted over landscape areas determined the surveyed area based on the studied organism. The studies usually covered a radius between 1-3 km which is assumed to be sufficient to avoid having pollinators overlapping study sites and is within the area that pollinators preferentially forage (Steffan-Dewenter *et al.* 2002). An example of a landscape study is by Rundlöf et al. (2014). A greater area with a high relative cover of red clover was selected as a landscape with MFCs and an area with low relative coverage was selected as control site and sampling was done at several points within the selected landscape (Rundlöf *et al.* 2014).

2.4. Theories and mechanisms

2.4.1. Local scale effects: Spill-over effects of mass flowering crops to semi-natural habitat

The spill-over effect describes the movement of organisms from one habitat into another nearby habitat. It is an important concept when discussing the effect of MFCs on pollinators as MFCs are expected to have positive spill-over effects on nearby SNH habitats (Blitzer *et al.* 2012). It is assumed that MFCs will attract pollinators because they provide a massive flowering resource, which will intrinsically contribute to more pollinators in adjacent habitats. Tscharntke et al. (2012) describes two concepts within spill-over theory: i) complementation and ii) supplementation. Complementation refers to how organisms can move between areas to obtain the resources they need, when all needed resources are not within the same area (Tscharntke *et al.* 2012). For example, in agricultural landscapes SNHs are less disturbed and pollinators can use this type of area for nesting, MFCs that are rich in floral resources can be seen as a food complement. Supplementation describes the addition of an area with a higher concentration of needed resources (Tscharntke *et al.* 2012). MFCs can for example be seen as a supplementation of a high-density floral area which provides pollinators with an abundance of food. MFCs are therefore both a complementation and a supplementation area in the landscape: MFCs provide pollinators with food resources to complement the nesting areas and are a supplementation due to the high concentration of flowers. The supplementation of MFCs in a landscape will affect the movement of pollinators in the landscape i.e. pollinators will move from SNH where they have their nest to MFCs to forage.

2.4.2. Landscape scale effects: Concentration and dilution effects

Concentration and dilution effects are concepts used within ecology to describe densities of species within fragmented landscapes. Concentration is defined as an increase of individuals within a habitat, usually it is specialised species that concentrate to areas where their specific food resource needs are met (Tscharntke *et al.* 2012). Dilution means individuals will disperse in a landscape where resources are sparse and concentrate in high-quality habitats resulting in individuals being divided unevenly across the landscape (Tscharntke *et al.* 2012). Concentration and dilution effects can be seen simultaneously. For example, in an agricultural landscape, pollinators are dispersed over a greater area to forage for food and when a MFC has its flowering peak, pollinators will concentrate in the MFC and will be unevenly dispersed over the landscape. If the habitat in which individuals concentrate in is the only habitat with the needed resources, and if this remains permanent, it may result in a loss of individuals, because habitats have a limited carrying capacity (Tscharntke *et al.* 2012). Dilution may have negative effect for plant pollination if pollinators are distributed unevenly in the landscape since there might not be enough pollinators to pollinate both crops and wildflowers resulting in less yield and a decreased survival of wildflowers. However, MFCs are not a permanent flowering resource and the dilution and concentration effects, will be temporary

3. Materials and Methods

3.1. Literature review process

To assess the effects of MFCs on pollinators I carried out a literature review of existing papers in a peer reviewed journal database “ISI, the web of science”. Because there are a lot of studies investigating the effect of land use on pollinators it was important to define relevant key words for the research. The research terms that were used were chosen and discussed before the literature review was done.

The criteria that each paper had to meet was that each paper had to have a study site with a MFC and a control site without a MFC. Each study had to either include measurements on abundances or density of pollinators and/or species richness of pollinators. A word search on the “web of knowledge” (ISI) was done with the words ““mass flowering”, “crops” & “pollinators” which gave a total hit of 173 articles. This review process led from the original 173 papers found with the word search to a total of 12 papers that complied with the requirements. In some cases, a paper included more than 1 “study” on wild pollinator abundances or species richness as some did studies in different countries and at different times (Appendix 3). Therefore, I have, from these 12 papers, yielded a total of 37 studies: 30 studies on wild pollinator abundances and 7 studies on pollinator species richness.

The papers had information on types of pollinators, separating managed, wild and hoverflies for abundances. Due to lack of information on abundances of hoverflies they were excluded and “wild pollinators” only refers to wild bee species and primarily bumblebees, even though abundance was measured for other bee species as well.

3.2. Article database

The terms abundance or density refer to the number of individuals of pollinators in total that were found in a certain area. Species richness or diversity refer to the total number of species found within the area. The site, area and method of collection varied between studies examined and this information was gathered and categorized. To measure the effect sizes of MFCs, means, standard deviation and number of replicates were extracted from the papers for both the area with MFC present and the control without the MFC (Appendix 3).

Selected relevant data from the articles was then categorized in Excel (Appendix 3). The variables used for categorization were: Crop, Crop sample, Control Site, Year, Study type, Country, Abundance Measure, Bloom, Distance, Effect with focal crop and Effect without focal crop (Table 1.). The variables made it easier to see differences between studies and what variables could yield different results.

Table 2.
The variables used to categorize relevant information in the literature review. The variables were used to easily and efficiently categorize data collected from the reviewed studies.

Variables used for categorization	Description
Crop	The crop type that was studied in each paper.
Crop sample	Where the study had sampled pollinators with MFC. The sampling could have been conducted in the crop, the field margin or in a SNH.
Control Site	Where the study had sampled pollinators without MFC. The sampling could have been conducted in a field margin, SNH or meadow.
Year	In what year the study was conducted.
Study type	Categorised if the study had been experimental or gradient. Experimental studies were studies with a sample site

	and a control site. Gradient studies sampled larger areas and used relative cover of MFC.
Country	In which country the study had been conducted.
Abundance measure	Categorisation of how abundance was measured in each study. The studies either used transects or traps and it was relevant to know the time for each transect and how large an area they covered. In the case of traps, I documented how many traps had been placed per site.
Bloom	Described if the sampling was conducted during the MFC bloom or after MFC bloom.
Distance	Categorization of which scales the studies were at. If the studies were at a local scale they were categorized as “edge”. If they were at a landscape scale the studies were categorized as “landscape”.
Effect plant with focal crop	The variable that contained means, SD and replicates of the studies with the effect of the MFC: abundance of honeybees, Wild pollinators and species richness were given separate variables within in this variable.
Effect plant without focal crop	The variable that contained means, SD and replicates of the control site from each study: abundance of honeybees, Wild pollinators and species richness were given separate variables within in this variable.

3.3. Data extraction

Using the selected 12 articles data on pollinator abundances or species richness was collected from either the result section or the supplementary data. In some studies, the data was only available in either raw form from supplementary material or in graphs. If the data was raw, calculations of the mean and SE were done in excel or R (R 3.5.2 GUI 1.70 El Capitan build).

If the data was not readily available and presented in graphs, image analysis would be used to extract the relevant information. Image analysis to extract data from graphs was used on 8 papers. The process of using image analysis was to take a snapshot of a graph within the reviewed studies containing information on abundance or species richness. Then in an image analysis program unknown graph values were converted to known values by measuring pixels. For example, the value of 2 could be a distance of 55 pixels. Then each bar that gave an interesting value could be measured in relation to 55 pixels. If a bar had 125 pixels then extracting the value would be 125/55x2. The program used to do this was ImageJ (ImageJ 1.52q).

3.4. Effect sizes

The data collection yielded means for two groups, a focal point with a MFC present and a control group without a MFC which were used to measure the effect size. I used Hedge's g to measure the effect size because it is more appropriate for smaller populations sizes and when sampling sizes vary between groups (Stephanie 2016a). I did the calculations in excel. First the pooled standard deviation for each study site was calculated, I used Cohen's formula for this (Stephanie 2016b):

$SDpooled= \sqrt{}(n_1\text{-}1)SD_1^2+(n_2\text{-}1)SD_2^2/\ n_1+n_2\text{-}2$

Then Hedge's g was calculated for each study site with the formula:

$$\text{Hedge's } g = (M_1 - M_2)/SDpooled$$

Hedge's g divides the difference between means of two sample groups, the group with MFC was placed first in the formula (M_1) and the control group second (M_2). This resulted in relative values that could be used for comparison between studies. The further away from 0 the greater the effect. Hedge's g value was calculated for wild pollinator abundances and species abundances. The data was transferred from excel to R studios (RStudio Version 1.2.5042) as a csv file. Forest plots were constructed to show the variance in estimates between studies using the following packages: *sjPlot* (Lüdecke D, 2020), *ggstance* (Lionel, 2020), *jtools* (Long JA, 2019) and *ggplot2* (H. Wickham, 2016).

4. Results

4.1. Literature review description

In this literature review data from 12 papers was extracted yielding 37 studies, 30 that measured wild pollinator abundances and 7 studies that measured pollinator species richness. Most reviewed papers were published between 2010 and 2020, with the exception of one study that was published 2003 (Figure 1). The studies were conducted in 9 different countries, the countries were either located in Europe or North America (Figure 2). Out of the 31 study sites 16 studies were conducted as gradient studies and 15 were conducted as experimental studies.

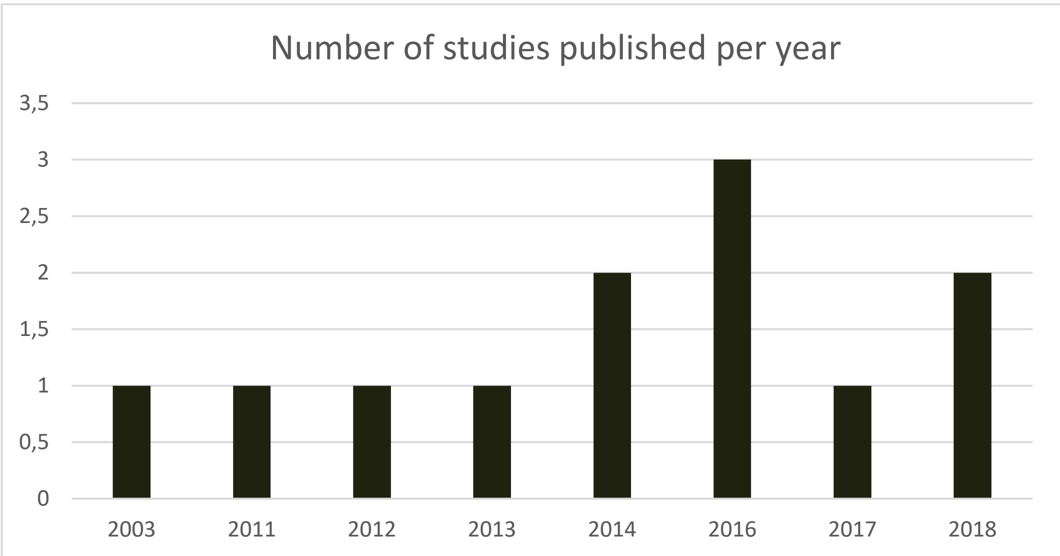

Figure 1.
Histogram showing in which years papers were published (N=12)

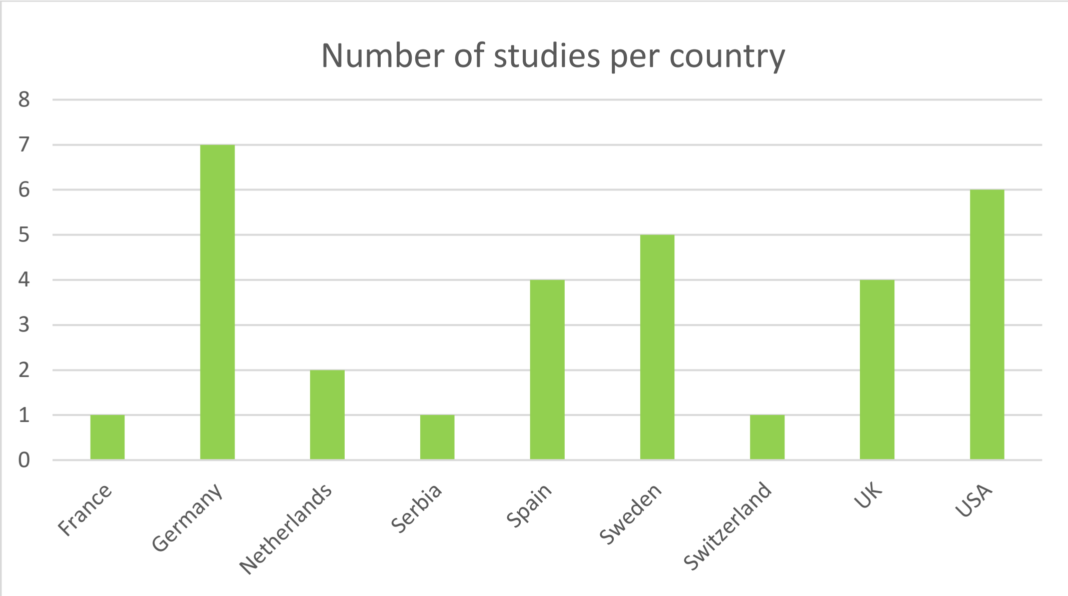

Figure 2 Histogram showing geographical location of studies (N=31)

Different crops were sampled for effect on pollinator abundances and species richness in the various studies, see *Figure 3*: oilseed rape, and sunflower, represent a majority of cases reviewed (15 and 8 respectively). Strawberries, faba beans and various ley types: clover and *Hedysarum* are also represented but to a lower degree. Oilseed rape was sampled in most countries included in this review except for the US, Switzerland and Serbia (see *Figure 4).*

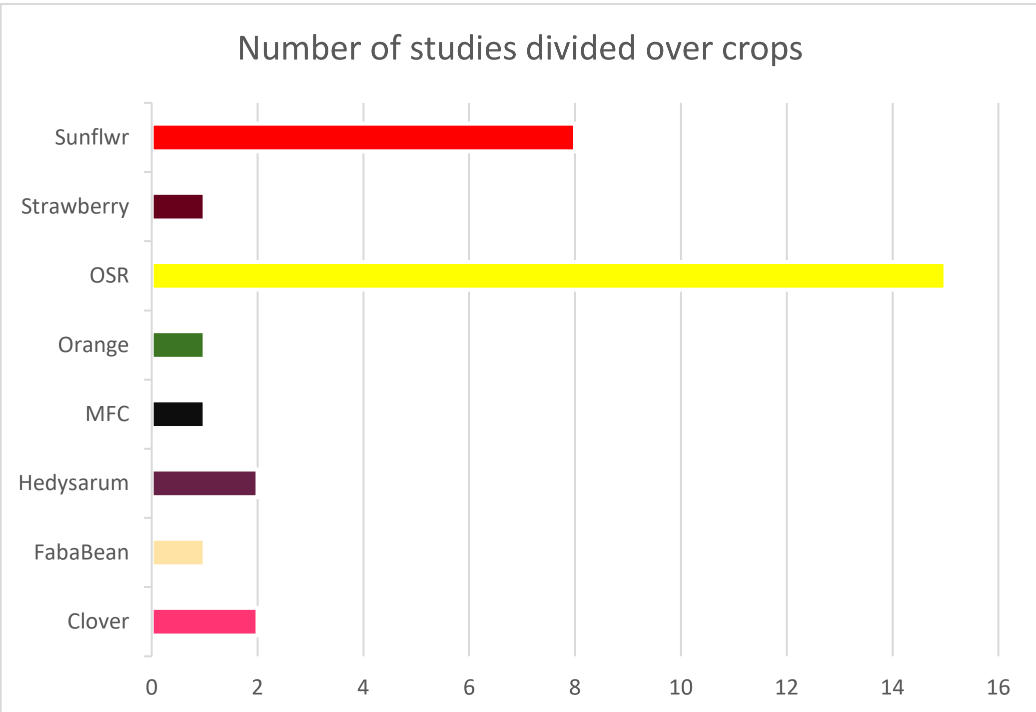

Figure 3.

The crops used as "mass flowering crops" in the studies. The variable MFC refers to one study that used all MFCs in the landscape as high/low coverage and includes oilseed rape, sunflower & clover. The abbreviations are: Sunflwr= Sunflower, OSR = Oilseed rape, MFC = Mass Flowering Crop, FabaBean = Faba bean (Vicia fabia), Orange = Citrus x sinensis

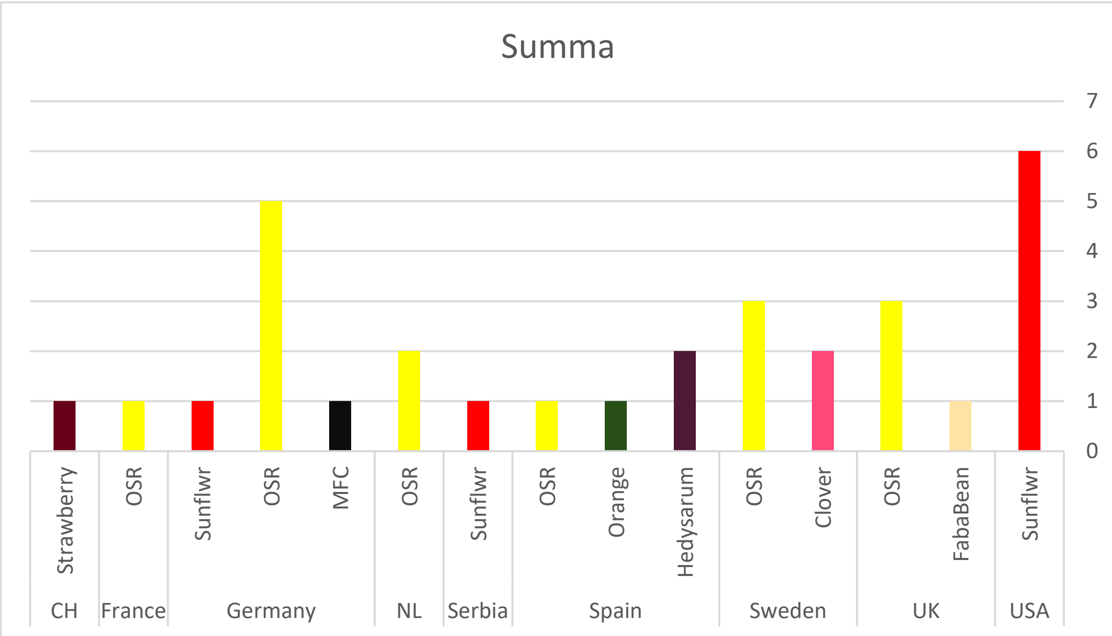

Figure 4.

Crop types and in which country they were sampled. The variable MFC refers to one study that counted all mass flowering crops in the landscape as high/low coverage and includes oilseed rape, sunflower & clover. The abbreviations are: Sunflwr= Sunflower, OSR = Oilseed rape, MFC = Mass flowering crop, FabaBean = Faba bean (Vicia fabia), Orange = Citrus x sinensis.

4.2. Effects of mass flowering crops on pollinators

Out of the 12 papers there were seven studies that measured species richness of pollinators. The crops that species richness was sampled in were *Hedysarum*, oilseed rape and strawberries (Figure 5a). Out of the seven, four were landscape and three local studies (Figure 5b). Four out of seven had of experimental study design and three gradient study design (Figure 5c). Six studies showed negative effects on pollinator species richness from MFCs and one study showed a positive effect size.

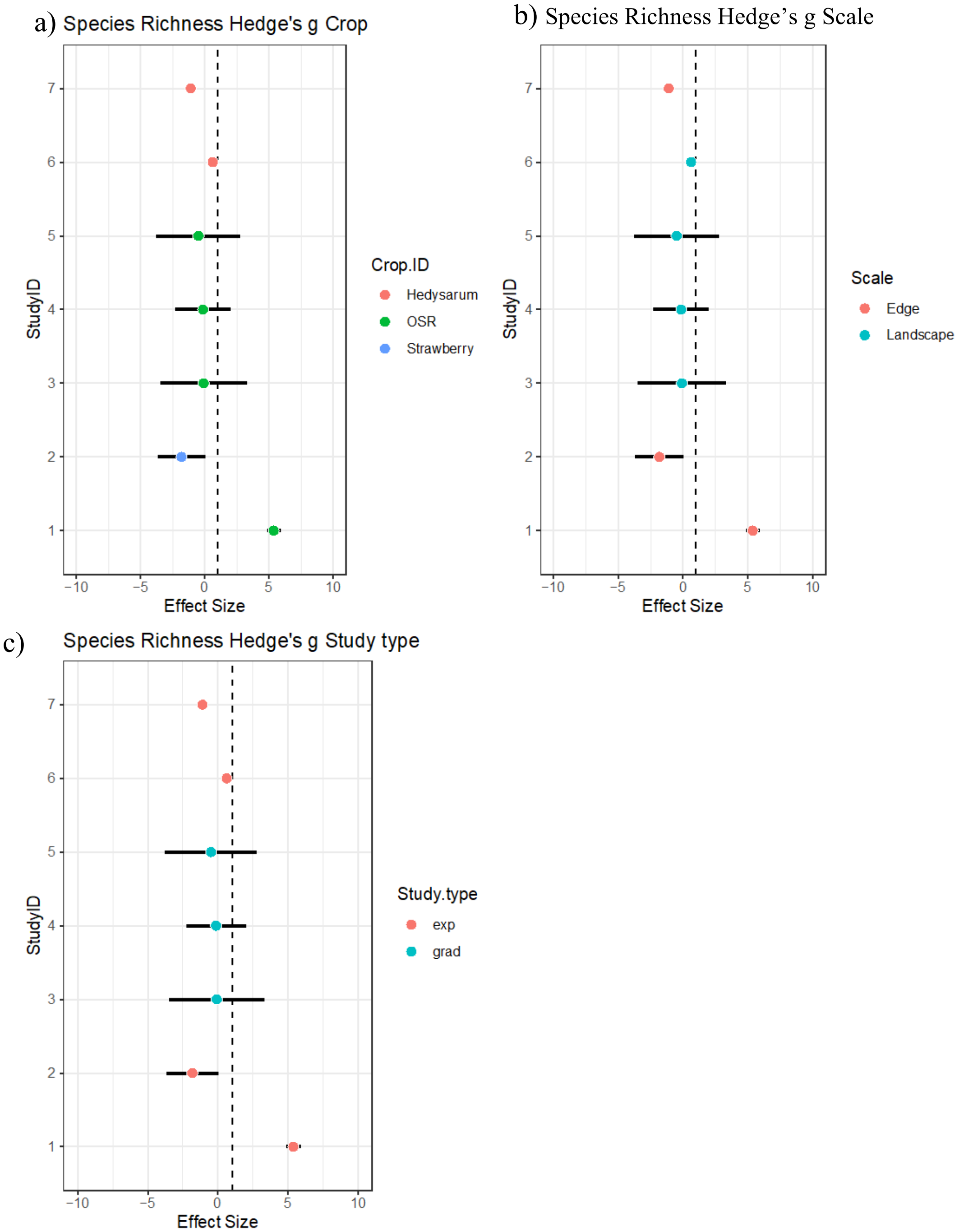

Figure 5.
Forest plots showing the effect sizes of mass flowering crops on pollinators species richness. Effect sizes were measured using Hedge's g, the further from zero each dot is the larger the effect. Each plot shows the correlation of a different variable; a. crops (abbreviations: OSR = oilseed rape), b. The scale at which the study was conducted (i.e. edge or landscape), and c. whether the study was experimental (exp) or gradient (grad).

There were 30 studies that measured wild pollinator abundances. 12 studies showed positive effect size on pollinator abundances from MFCs, 18 showed negative effect (Figure 6, Appendix 2). Out of these 12 positive findings, 9 were of experimental study design (Figure 6c, Appendix 2). Out of the 18 that showed negative effect on abundances 16 were landscape studies (Figure 6b). Out of the 18 that showed negative effects on abundances 14 were gradient studies (Figure 6c). The crops that showed greatest effect on abundances were sunflower, clover and strawberry (Figure 6a). Oilseed rape was the most frequent crop used in the studies, but generally showed relative low effect on abundances. The highest negative effect size was shown by a study on strawberries.

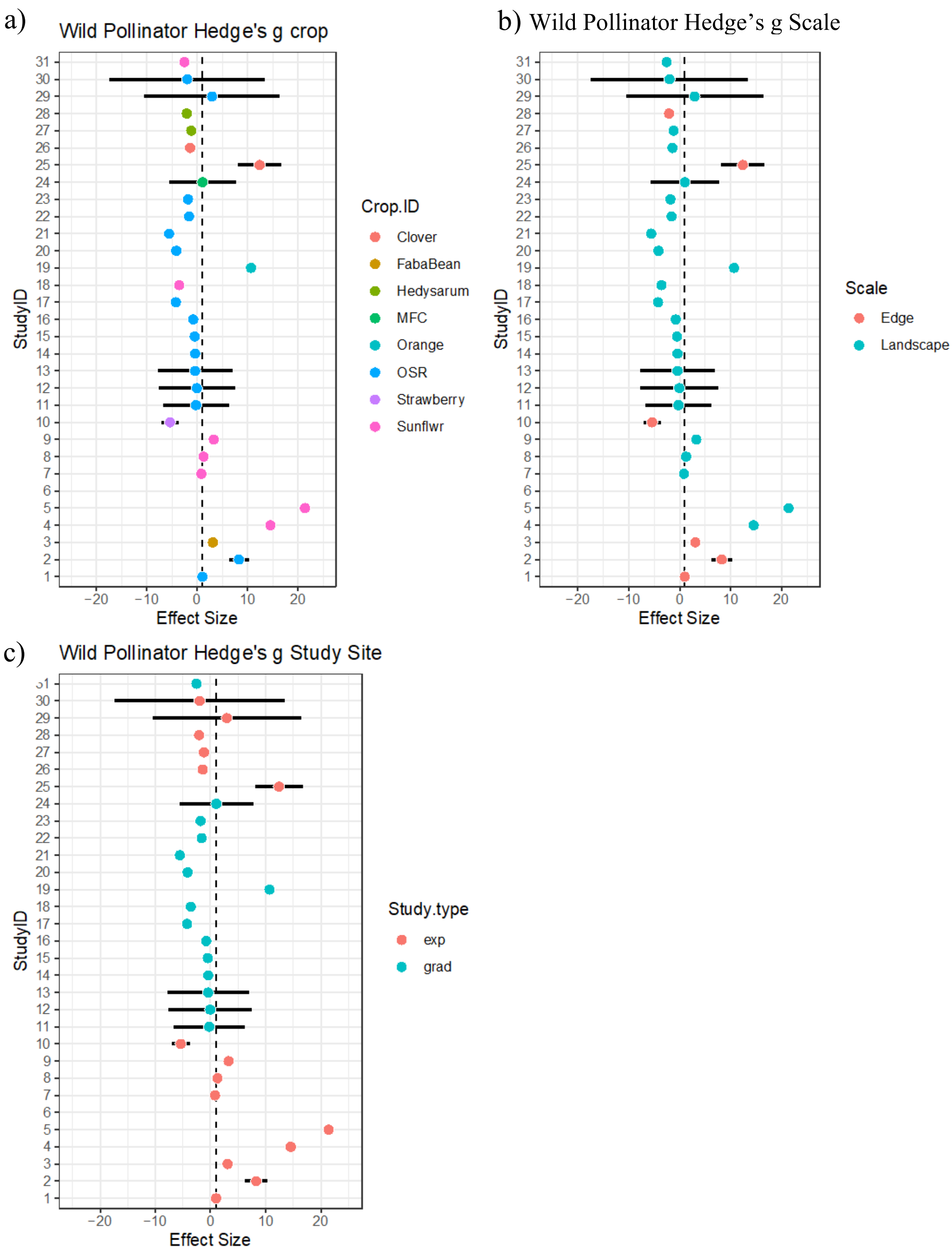

Figure 6.

Forest plots showing the effect sizes of mass flowering crops on pollinator abundances. Effect sizes were measured using Hedge's g, the further from zero each dot is the larger the effect. Each plot shows the correlation of a different variable; a. crops (abbreviations: OSR = oilseed rape, MFC = mass flowering crops, Sunflwr = sunflower, FabaBean = faba beans, Orange = Citrus x sinensis), b. The scale at which the study was conducted (i.e. edge or landscape), and c. whether the study was experimental (exp) or gradient (grad).

5. Discussion

5.1. Experimental design and phenology effects

The effect of MFCs on pollinator abundances and species richness varied and were both positive and negative.

5.1.1. Pollinator abundances

The studies that showed positive effects on abundances were mostly studies done with an experimental study design (Figure 6c). This indicates that the presence of a MFC can benefit pollinators more than the absence of a MFC, since experimental studies were done with either the presence or absence of MFCs. 9 out of 15 experimental studies showed positive effects on abundances (Figure 6c). One reason why the positive effect can be seen for wild pollinator abundances could be because MFCs provide wild pollinators with a high-quality flowering resource which is absent at the control site. For example Todd et al. (2016) compared the abundance of pollinators in the peak flowering season of sunflower compared to a wild meadow. The blooming sunflowers providing pollinators with a high-density floral resource, whereas for the control the density of flowers was probably lower (Figure 6, studyID: 4-9). So, the presence of MFCs can benefit wild pollinator abundances more than the absence, because it provides pollinators with a high flowering resource.

In contrast studies with a gradient design showed mostly negative effects on abundances, except for 1 study out of 15 that showed positive effects (Figure 6c). This could be because the difference for high/low relative coverage of MFC might not have been distinct enough. For example Westphal *et al.* (2003) concluded that increasing coverage of oilseed rape benefitted bumblebees abundances, however in this study the effect is only slightly positive (Figure 6 study.ID:24, Appendix 2), indicating that the way the control of low coverage is not distinct enough from the high coverage. For this study high coverage of MFC is when the study is over 7.8 per cent and low is below 7.8 percent

(Appendix 3). This indicates that there is a problem with the methodology for gradient studies making the effects less reliable.

Another reason for the observed positive effects of MFC on wild pollinator abundances could be due to crop phenology as 5 out 8 studies that show positive effects are late flowering crops (see Figure 6a. for crop effect, Table 1. for phenology). Rundlöf et al. (2014) showed that late flowering red clover had positive effects on bumblebee abundances, specifically the abundance of males and new queens increased. Late flowering MFCs being beneficial for queens and males could explain the positive effects seen from sunflowers in this study (Figure 6a). The positive effect could also be explained by Schellhorn et al. (2015) theory on continuous flowering resources being beneficial for abundances. Late flowering MFCs provide valuable flowering resources when other MFCs, such as oilseed rape are no longer in bloom, providing pollinators with another large resource pulse. Late flowering MFCs could be beneficial for abundances because they increase abundance of queens and males and make the flowering resources more continuous throughout the season. This effect is more relevant for bumblebees that have longer colony lifecycles and is a valid explanation for the results presented as most studies measured bumblebee abundances (Appendix 3).

5.1.2. Pollinators species richness

The review indicates that type of crop could also explain the negative effects seen on pollinator species richness. 6 out 7 studies showed negative effects on pollinator species richness (Figure 5a.). The reason for the negative effect could be explained by what Goulson et al. (2005) showed: that it is mainly generalist pollinators that benefit from MFCs. The logic being that MFCs provide a high-quality resource for certain species, but the species that cannot use this resource will not benefit, limiting the positive effect to few species. Oilseed rape is described as a crop that will benefit generalist pollinators (Goulson et al. 2005), therefore it is surprising that oilseed rape was the only crop that showed positive effects on pollinators species richness (Figure 5a, studyID: 1). This could, perhaps, be explained by there being a lower diversity of flowers at the control. Since the study was an edge and experimental study (Figure 5, studID:1), it is possible that the MFC sampling edge had a greater diversity of flowers than the control promoting diversity of pollinators at the MFC. Hedysarum, which is a legume, showed negative effects, the negative effects could be attributed to the idea that one type of flower will only benefit a limited number of species, those specialized on long tube flowers. Indeed, Goulson et al. (2005) shows that legumes benefit long-tongued bumblebees that are described as specialists over more generalist short tongue pollinators.

Unfortunately, because of the low number of studies and high variability in this study it was not feasible to distinguish between different functional pollinators groups. MFCs had mostly negative effects on pollinator species richness except one study with oilseed rape.

5.2. Dilution and Spill-over effects

There is indication of dilution effects on pollinator abundances when MFCs are present. The majority of the gradient and landscape studies showed a negative effect on pollinator abundances (Figure 6b&6c). This could be evidence of dilution effects as Holzschuh et al. (2011) described where the available pollinators in the landscape are dispersed over oilseed rape leading to a decrease in pollinators density in non-mass flowering crop habitats. The reason why this could indicate dilution effects is that gradient and landscape studies used multiple sampling sites within landscapes, mostly in SNH. The wild pollinators will move to the attractive high flower dense MFCs and concentrate there, leading to a decrease of pollinators in the SNHs where abundances were measured. This dilution could affect wildflower pollination as it indicates competition between flowering crops and wildflowers (Holzschuh et al., 2011). To conclude, this review indicates that MFC can lead to dilution effects as wild pollinators are not spread equally over the landscape, but will instead aggregate in the mas flowering crop, which could have negative effects for wild plant pollination. However, this is based on the negative effects shown by gradient studies, which could be misleading due to how the separation of high/low coverage of MFC was done.

There is evidence of positive spill-over from MFCs, as a majority of the edge studies showed positive effects on pollinator abundances. Spill-over effects can be seen in the edge studies on abundances as the edge studies show how the nearby presence of a MFC affected the abundance of pollinators in field margins. From the 6 edge studies reviewed, 4 had positive, 2 had negative on pollinator abundances (Figure 6b, Appendix 2), this indicates that there could be beneficial spill-over effects from MFCs. However, the positive effects could be attributed to the differences between the edges. If the edges are rich in flowers this could affect abundances too and this has not been analysed in this review. As for species richness, the edge studies show more negative effects than positive (Figure 5b). From spill-over theory the negative effect on species richness could be explained by the argument that MFCs benefit fewer species and these species could be the ones represented in the edges. MFCs could promote spill-over to field margins and edges, however MFCs could also contribute to changing the species composition to a less diverse one.

5.3. Limitations

To improve upon this research, discussing its limitations is vital. Among the first limitations to the generalisability of the results are the variables investigated. This study only reviews how MFCs affect wild pollinator abundances and species richness and does not include how other variables could affect abundances and richness. MFCs will not be the only or the main flowering resource in the landscape as SNH can also provide flowering resources, and the coverage and quality of SNH will affect abundances and species richness of pollinators (Tscharntke *et al.* 2012). Therefore, it would be interesting to include SNH as a variable in future studies. For example as Westphal et al. (2003), who measured both SNH and MFC coverage to see how bumblebee densities corresponded to an increasing coverage of both. The wildflower composition could also affect pollinator species richness with greater diversity of flowers promoting greater diversity of pollinators. Another variable that would be interesting to integrate is post-blooming MFCs, resource continuity as Schellhorn et al. (2015) discussed could improve both abundances and survival of organisms. This could be tested by looking at late flowering MFC that also have early flowering MFC in the near area. Integrating SNH quantity and quality and late-flowering MFCs with early flowering MFCs as variables could give more information on MFCs effects on pollinator abundances and species richness.

Further limitations concern the search terms and methodology used to obtain data. The articles reviewed were all gathered from one search engine, "ISI web of science", which limits articles found. If more search engines were used, more articles could have been found, providing more data to use in analyses. The limitation of studies to analyse was more limiting for species richness with only 7 studies. Another problem is how the data was gathered, this review looked at species richness at different study sites as well as wild pollinator abundances, the data was not detailed and some studies did not separate managed and non-managed pollinators, leading to some studies having greater abundances and making the results harder to compare. If more articles had been found through the utilisation of more search engines and if data could have been sorted clearer, stronger evidence for effects may have been found.

Conclusions

It seems like there is a tendency for local scale positive effects from MFCs on pollinator abundances, but that MFCs do not appear to promote pollinator species richness, however more research is needed to be certain of the effects. Some trends could be seen: the presence of MFCs appears to have some positive effects on pollinator abundances compared to the absence of MFCs. A trend which is more notable closer to the crops and could be explained by spill-over of pollinators from the MFCs. Crop phenology also showed effects on abundances, specifically late-flowering crops showing positive effects which could be attributed to them providing a continuous resource and because late mass flowering crops can increase the abundances of bumblebee males and new queens. MFCs showed negative effects on pollinator species richness and could be explained by MFCs being monocultures and do not provide a diversity of flowers. There was indication of MFCs causing a dilution of pollinator abundances, but due to the methodology of how high/low relative coverage of MFC was done this is uncertain. However, this study would have given more information if the quality and quantity of SNH was included. A more in-depth review that regards SNH coverage and gathers data more precisely and includes more articles is necessary to draw conclusions of the effect of MFCs on wild pollinators.

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Appendix 1

Table 3 Pollinator species richness used to make Forest plots in R studios

Article.ID	**Year**	**Study.Id**	**Crop.ID**	**Study.type**	**Country**	**Scale**	Rich_Pooled SD	Rich_Hedges
3	2013	1	OSR	exp	France	Edge	0,5311152	5,3744468
13	2016	6	Hedysarum	exp	Spain	Landscape	0,0655057	0,6228463
13	2016	7	Hedysarum	exp	Spain	Edge	0,0579396	-1,0955933
7	2018	2	Strawberry	exp	Switzerland	Edge	1,8666617	-1,8224347
8	2017	3	OSR	grad	Germany	Landscape	3,3955854	-0,0861227
8	2017	4	OSR	grad	UK	Landscape	2,1389589	-0,1394266
8	2017	5	OSR	grad	Sweden	Landscape	3,2800152	-0,4953833

Appendix 2

Table 4 MFCs study type, crop type, scale & country with hedge's g

Study.ID	Group	Crop.ID	Study.type	Country	Scale	WildP_Hedges.g	WildP_PooledSD	Rich_Pooled SD	Rich_Hedges
1	1	OSR	exp	Spain	Edge	1,002472	167,0662	NA	NA
3	2	OSR	exp	France	Edge	8,275505	1,986307	0,531115	5,374446777
4	3	FabaBean	exp	UK	Edge	3,078484	0,412311	NA	NA
5	4	Sunflwr	exp	USA	Landscape	14,53748	0,65199	NA	NA
5	5	Sunflwr	exp	USA	Landscape	21,39498	0,659425	NA	NA
5	6	Sunflwr	exp	USA	Landscape	NA	NA	NA	NA
5	7	Sunflwr	exp	USA	Landscape	0,816491	0,17	NA	NA
5	8	Sunflwr	exp	USA	Landscape	1,263049	0,204092	NA	NA
5	9	Sunflwr	exp	USA	Landscape	3,269203	0,160733	NA	NA
7	10	Strawberry	exp	Switzerland	Edge	-5,40142	1,655249	1,866662	-1,822434749
8	11	OSR	grad	Germany	Landscape	-0,23998	6,499111	3,395585	-0,086122698
8	12	OSR	grad	UK	Landscape	-0,06692	7,6193	2,138959	-0,139426641
8	13	OSR	grad	Sweden	Landscape	-0,42909	7,392121	3,280015	-0,495383327
9	14	OSR	grad	Germany	Landscape	-0,41587	0,285044	NA	NA
9	15	OSR	grad	Germany	Landscape	-0,51804	0,762758	NA	NA
9	16	OSR	grad	Netherlands	Landscape	-0,77745	0,133417	NA	NA
9	17	OSR	grad	Netherlands	Landscape	-4,24386	0,264197	NA	NA
9	18	Sunflwr	grad	Serbia	Landscape	-3,57358	1,041939	NA	NA
9	19	Orange	grad	Spain	Landscape	10,67005	0,497211	NA	NA
9	20	OSR	grad	Sweden	Landscape	-4,16452	0,180278	NA	NA
9	21	OSR	grad	Sweden	Landscape	-5,58466	0,173349	NA	NA
9	22	OSR	grad	UK	Landscape	-1,61176	0,405216	NA	NA
9	23	OSR	grad	UK	Landscape	-1,81784	0,932209	NA	NA
11	24	MFC	grad	Germany	Landscape	1,035722	6,677053	NA	NA
12	25	Clover	exp	Sweden	Edge	12,38371	4,3214	NA	NA
12	26	Clover	exp	Sweden	Landscape	-1,42564	0,264128	NA	NA
13	27	MFC	exp	Spain	Landscape	-1,1946	0,515655	0,065506	0,622846324
13	28	MFC	exp	Spain	Edge	-2,09017	0,108167	0,05794	-1,095593253
14	29	OSR	exp	Germany	Landscape	2,936533	13,4421	NA	NA
14	30	OSR	exp	Germany	Landscape	-1,98246	15,45	NA	NA
15	31	Sunflwr	grad	Germany	Landscape	-2,55638	26,04237	NA	NA

Appendix 3

See attached excel file