



MAJOR REVIEW

Field margin floral enhancements increase pollinator diversity at the field edge but show no consistent spillover into the crop field: a meta-analysis

JORGE ZAMORANO,^{1,2} IGNASI BARTOMEUS,³ AUDREY A. GREZ² and LUCAS ALEJANDRO GARIBALDI^{4,5}

¹Programa de Doctorado en Ciencias Silvoagropecuarias y Veterinarias, Universidad de Chile, Santiago, Chile, ²Facultad de Ciencias Veterinarias y Pecuarias, Universidad de Chile, Santiago, Chile, ³Estación Biológica de Doñana (EBD-CSIC), Sevilla, Spain, ⁴Universidad Nacional de Río Negro, Instituto de Investigaciones en Recursos Naturales, Agroecología y Desarrollo Rural, Río Negro, Argentina and ⁵Consejo Nacional de Investigaciones Científicas y Técnicas, Instituto de Investigaciones en Recursos Naturales, Agroecología y Desarrollo Rural, Río Negro, Argentina

Abstract. 1. Conventional intensification of agriculture has reduced the availability of resources for pollinators, reducing their diversity and affecting plant pollination, both in natural habitats and croplands. Field margin floral enhancements such as flower strips or restored field margins could counteract these negative effects.

2. The approaches to assess the success of these management measures generally evaluate separately the pollinator response at the edge and within the crop, as proxies for pollinator conservation and pollination services, respectively.

3. We performed a meta-analysis to understand the influence of field margin floral enhancements on the abundance and richness of pollinators at the edge and within the field, and on crop yield.

4. We estimated 137 effect sizes from 40 studies, all from the northern hemisphere. Overall, the field margin floral enhancements increased the abundance and richness of pollinators at the field edge but had no consistent effect in the interior of the crop fields. Few studies evaluated crop yield, and in these studies no effects were observed.

5. These results suggest that field margin floral enhancements can constitute a positive conservation action for pollinators but not necessarily associated with pollination ecosystem service.

Key words. agroecosystem, conservation tool, floral margins, hedgerows, meta-analysis, pollination service.

Introduction

A large part of the area originally occupied by many temperate and tropical natural terrestrial ecosystems has become agricultural land (Ramankutty *et al.*, 2008) and the expansion and intensification of agriculture have greatly reduced local biodiversity (Foley *et al.*, 2005). This reduction of biodiversity directly affects a plethora of different ecosystem processes, both in the remaining natural habitats and in the crops itself (Tilman *et al.*, 2001; Oliver *et al.*, 2015). For example, agricultural intensification has reduced the availability of resources for pollinators

(Tscharntke *et al.*, 2005), which has led to a decrease in the abundance and diversity of pollinators in agroecosystems (Goulson *et al.*, 2015). This lack of pollinators in agricultural fields can result in poor pollination, as well as in a reduction in crop yields (Garibaldi *et al.*, 2009). To persist in agricultural habitats, wild pollinators must be able to find suitable nesting and foraging resources (Kremen *et al.*, 2004; M'Gonigle *et al.*, 2015). Because of this, the re-diversification of agricultural areas has been proposed as a mean to strengthen pollination services provided by wild pollinators (Tscharntke *et al.*, 2005; Kremen *et al.*, 2007; Winfree, 2010; Garibaldi *et al.*, 2014). Diversification of agricultural landscapes can take place at many scales, including within crops (e.g., polyculture), field margin floral enhancements (e.g., hedges and wildflower plantations) or landscape features (e.g., increasing natural coverage percentage) (Kremen & Miles, 2012; Duru *et al.*, 2015).

Correspondence: Jorge Zamorano, Programa de Doctorado en Ciencias Silvoagropecuarias y Veterinarias, Campus Sur, Universidad de Chile, Santiago, Chile. E-mail: jorge.zamorano@upla.cl

The use of field margin floral enhancements is one of the most extended practices to buffer the impact of intensive agriculture and conserve wild pollinators within their natural habitats (Sardiñas & Kremen, 2015). For example, best management practices recommended to introduce floral margins as additional sources for foraging and refuge for pollinators within monoculture landscapes (Pywell *et al.*, 2011a). In this sense, it has been found that the restoration of hedges increases the richness of pollinators in the edges of the fields (Hannon & Sisk, 2009; Carvell *et al.*, 2011). Floral field margins are the most common remnants of semi natural vegetation in crops (Marshall & Moonen, 2002; Boutin *et al.*, 2002; Dover, 2019). These are linear features of trees, shrubs and grasses that surround the crop. They can be remnants of existing vegetation from cleared lands, result from natural dispersal of plants or can be established through direct sowing (Long & Anderson, 2010). Moreover, a particular action that is gaining traction for habitat restoration in pollinator dependent crops is the use of flower strips, which are typically planted in the marginal areas adjacent to the crop (Wratten *et al.*, 2012; Morandin & Kremen, 2013b). Among its benefits are pest control, enhancement of the soil fauna, reduced soil erosion, sediment retention, increased biodiversity and air and water quality (Kort *et al.*, 1998; Kleijn *et al.*, 2006; Smith *et al.*, 2008; Whitehouse *et al.*, 2018). In addition, the value of this vegetation has been widely recognised as a habitat for native species of plants, butterflies and birds within agricultural landscapes (Burel, 1996; Maudsley, 2000; Dover *et al.*, 2000; Hinsley & Bellamy, 2000).

The effects of field margin floral enhancements can be evaluated for different target benefits. For example, several of these assessments focus on pollinator assemblages in the crop edge (Pywell *et al.*, 2006; Haenke *et al.*, 2009; Lye *et al.*, 2009; Potts *et al.*, 2009; Morandin & Kremen, 2013a; Morandin *et al.*, 2016; Campbell *et al.*, 2017; Wood *et al.*, 2018), while others study pollinator assemblages within fields (Morandin & Kremen, 2013b; Barbir *et al.*, 2015; Feltham *et al.*, 2015; Sardiñas & Kremen, 2015; Morandin *et al.*, 2016; Rundlöf *et al.*, 2018). When studying the effects of field margin floral enhancements on pollinating insects at the edge of the field, the information obtained from this approach is mainly related to the conservation of these organisms in agroecosystems, and, on the other hand, when assessing the diversity of pollinators within of crops, the focus is in enhancing the ecosystem services provided (Kremen *et al.*, 2019). Moreover, the characteristics of the edges also vary depending on the management, for example, edges can be restored or unrestored (i.e. sown and pre-existing plants, respectively) (Feber *et al.*, 1996; Blake *et al.*, 2011; Klein *et al.*, 2012; Sardiñas & Kremen, 2015), and also vary in the type of vegetation, which can range from arboreal vegetation to herbaceous type (Scheper *et al.*, 2015; Williams *et al.*, 2015; Caudill *et al.*, 2017; Garratt *et al.*, 2017).

Such differences could affect the magnitudes of the effects of field margin floral enhancements, both on pollinators and crop yield (Kremen *et al.*, 2019). Hence, it is necessary to evaluate the studies developed so far to determine whether there are differences in the effect of these management measures due to different spatial and ecological approaches, so in this study, we seek

to answer through a meta-analysis: What is the effect of field margin floral enhancements on the diversity of pollinators? Are pollinator responses different at the edge and within the field? Do these effects vary depending on the pollinator taxonomic group? And, do field margin floral enhancements affect crop yield?

Materials and methods

Literature search and study selection. A search of the published literature on the effect of field margin floral enhancements on pollinators was conducted using the Web of Science core collection database available from 1975 to May 2019 for the Electronic Library of Scientific Information program of the National Agency for Research and Development of Chile, which has access to a collection of almost 6000 scientific and technological journals in the English language. We use the combinations pollinat*ANDhedgerowANDcrop, pollinat*ANDfield marginANDcrop, pollinat*ANDhedgerowANDagro*, pollinat*ANDfield marginANDagro*, pollinat*ANDedgeANDcrop, pollinat*ANDedgeANDagro*, pollinat*ANDflower stripANDcrop, pollinat*ANDflower stripANDagro*. From these search criteria, a total of 447 studies were obtained. Additionally, a search was made in the database of Scheper *et al.* (2013) (71 studies) and Dover (2019) (204 studies), which reviewed studies that evaluate pollinator responses to changes in crop edge vegetation, both reviews did not assess the effect of field margin floral enhancements, but included these studies to evaluate other objectives, such as the influence of agri-environmental schemes.

The inclusion of studies in our meta-analysis was based on the following criteria:

1. A field study that evaluates the effect of field margin floral enhancements on the pollinator diversity on the edge or within the crop.
2. The response variables consider the abundance, richness, visitation rate of pollinators, and/or crop yield.
3. Mean, standard deviation (or standard error) and sample size are reported. For those studies that reported their results only in graphs, data were obtained using DATATHIEF II software (B. Tummers 2006 <<https://datathief.org/>>).
4. Includes a comparison between an experimental and a control group. When comparisons were made between more than two treatments, the extreme groups were used for comparison. For example, in studies comparing the diversity of pollinators at different distances from the crop edge, the experimental treatment was the site closest to the edge and the control was the site further away from the edge (three studies) and generally there are no significant differences between the survey distances within the field. In the case that the study was carried out over several years, only the data from the last year were used (seven studies).

Treatments compare always sites with field margin floral enhancement (experimental group) and sites without field margin floral enhancement (control group) (Fig. 1). The control treatments can include fields with edges managed with monofloral strips, edges without hedges or floral strips, and in the case

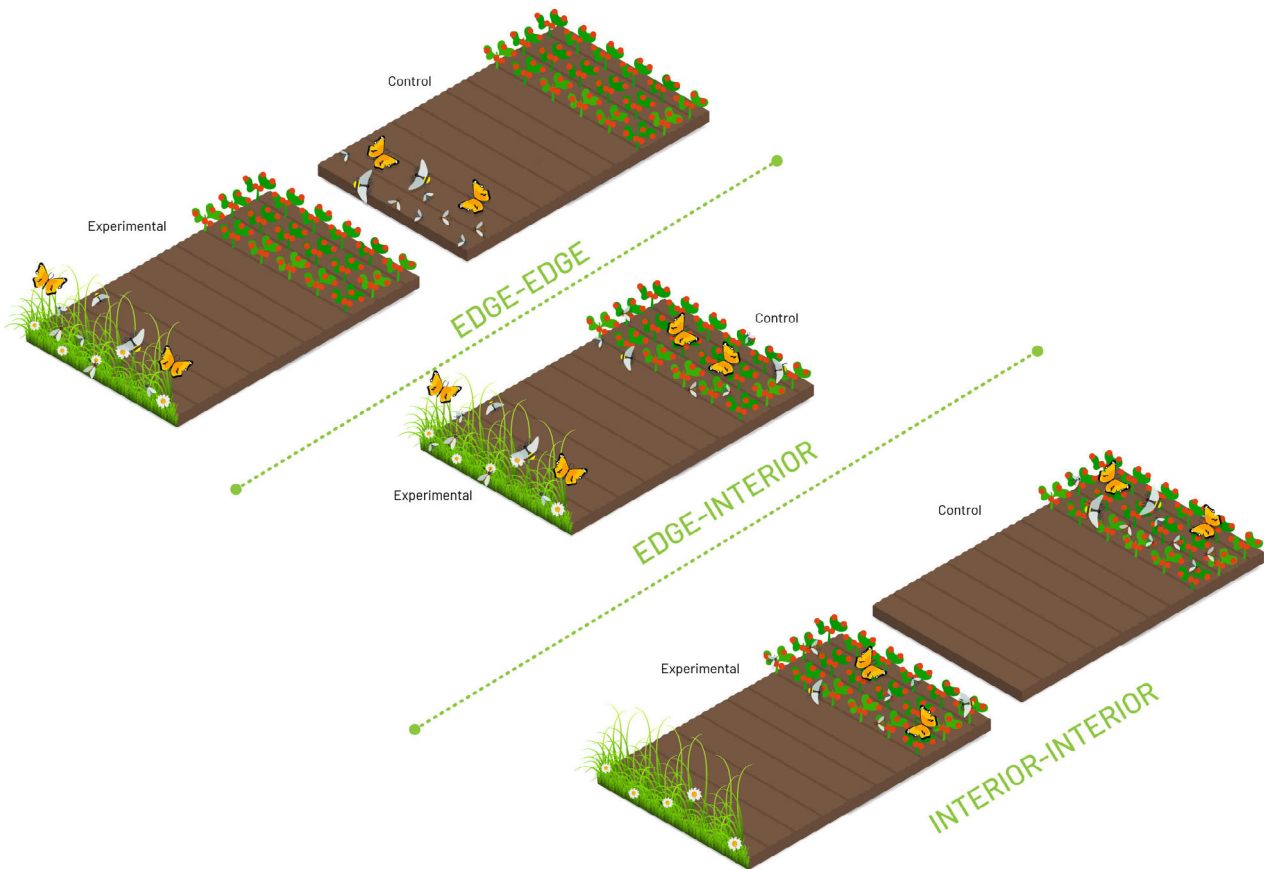


Figure 1. Graphical representation of the three contrast types considered in our meta-analysis to understand the effects of field margin floral enhancements. Edge-edge when crop edges of different fields were compared, edge-interior when the edge of the crop was compared with the inside of the same field, and interior-interior when sites within crops were compared between different fields. The insects depict the sampling locations. [Color figure can be viewed at wileyonlinelibrary.com]

of edge-interior contrast, the interior of the crop with a conventional management. Each study was categorised based on: (i) contrast type: edge-edge (EE), when crop edges of different fields were compared; edge-interior (EI), when the edge of the crop was compared with the inside of the same field, and interior-interior (II) when sites within crops were compared between different fields (Fig. 1 and Table 1). (ii) Edge management: restored (e.g., fields with edges with a mix of sown floral strips or hedgerows restored with native or exotic vegetation) and unrestored (e.g., forest edges) (iii) edge type: edges dominated by herbaceous, arboreal or shrubby vegetation. (iv) Pollinator taxa evaluated: butterflies, bumblebees, honeybees, hoverflies, wild bees (i.e. studies including all apoidea) or other wild pollinators (i.e. studies including all pollinator taxa). The response variables were abundance, species richness and visitation rate for each pollinator taxa and the crop yield (Table 1).

Effect sizes. Mean, standard deviation and sample size for the experimental and control groups of each study were recorded. For each study, the Hedges' d index was calculated as

a measure of the effect size. Hedges' d is an estimate of the standardised mean difference between the control and experimental groups that is not biased by small sample sizes and unequal sampling variances (Hedges & Olkin, 1985). Hedges' d is an index without units that calculates the magnitude of the effect and its direction. The highest effect sizes are those that show large differences between the control and experimental groups. For example, positive d values indicate a tendency to increase the response variables (e.g. abundance of visiting pollinators) in edges with field margin floral enhancements (Borenstein *et al.*, 2009).

Statistical analyses

For each response variable, a mixed-effects model was carried out using edge management, edge type and pollinator guild as moderators of the effect, except for the crop yield in which a random effect model was used because the analysis does not present moderators due to the low number of studies for this variable, which include only restored edges and herbaceous plants.

Table 1. Detail of 40 studies used in the meta-analysis, moderators and levels are indicated for the estimation of effect sizes.

Authors and Year	Country	Crops	Contrast	Survey distance within field (m)	Edge management	Edge type	Response variable	Pollinators
Feber <i>et al.</i> (1996)	England	Not reported	EE	NA	Restored	Herbaceous	Abundance Richness	Butterflies
De Snoo <i>et al.</i> (1998)	Netherlands	Potato, Wheat	EE	NA	Unrestored	Herbaceous	Abundance Richness	Butterflies
Pywell <i>et al.</i> (2005)	England	Cereals	EE	NA	Unrestored	Herbaceous	Abundance Richness	Bumblebees
Pywell <i>et al.</i> (2006)	England	Cereals	EE	NA	Unrestored	Herbaceous	Abundance Richness	Bumblebees
Haenke <i>et al.</i> (2009)	Germany	Wheat	EE	NA	Unrestored	Herbaceous	Abundance Richness	Hoverflies
Hannon and Sisk (2009)	USA	Alfalfa	EI	6 Between 400 and 600	Unrestored	Arboreal Shrubs	Abundance Richness	Wild bees
Lye <i>et al.</i> (2009)	Scotland	Fescue Sorghum Grasses	EE	NA	Unrestored	Herbaceous Shrubs	Abundance	Bumblebees
Merckx <i>et al.</i> (2009).	England	Not reported	EE	NA	Unrestored	Arboreal	Abundance	Butterflies
Potts <i>et al.</i> (2009).	England	Grasses	EE	NA	Restored	Herbaceous Herbaceous	Abundance Richness	Bumblebees Butterflies
Holzschuh <i>et al.</i> (2010)	Germany	Wheat	EE	NA	Unrestored	Herbaceous	Richness	Wild bees
Blake <i>et al.</i> (2011)	England	Barley Beans Oilseed rape Rye Wheat	EI EE	NR NA	Restored	Herbaceous	Abundance Richness	Butterflies
Pywell <i>et al.</i> (2011b)	England	Oilseed rape Wheat	EE	NA	Restored	Herbaceous	Abundance Richness	Wild pollinators
Walton and Isaacs (2011)	USA	Blueberry	EE	NA	Restored	Herbaceous	Abundance	Hoverflies
Klein <i>et al.</i> (2012)	USA	Almonds	EI	50–110	Unrestored	Shrubs	Visit rate	Wild bees Honeybees Hoverflies Wild bees
Morandin and Kremen (2013a)	USA	Alfalfa	EE	NA	Restored	Shrubs	Abundance Richness	Wild bees
Morandin and Kremen (2013b)	USA	Tomato Wheat Tomato	II EE	10–100-200* NA	Restored	Shrubs	Abundance Richness	Honeybees Hoverflies Wild bees
Blaauw and Isaacs (2014)	USA	Blueberry	II	15	Restored	Herbaceous	Visit rate Yield	Honeybees Hoverflies Wild bees
Barbir <i>et al.</i> (2015)	Spain	Coriander	EE II	NA NR	Restored	Herbaceous	Visit rate Yield	Hoverflies Wild bees
	Scotland	Strawberry	II	100	Restored	Herbaceous	Abundance	

(continued)

Table 1. (continued)

Authors and Year	Country	Crops	Contrast	Survey distance within field (m)	Edge management	Edge type	Response variable	Pollinators
Feltham <i>et al.</i> (2015)								Wild pollinators
Pywell <i>et al.</i> (2015)	England	Beans Oilseed rape Wheat	EE	NA	Restored	Herbaceous	Abundance	Wild bees
Sardiñas and Kremen (2015)	USA	Sunflower	EE	NA	Unrestored	Arboreal	Abundance	Wild bees
			EI	10–50–100–200			Richness	
			II	10–50–100–200				
Scheper <i>et al.</i> (2015)	England	Not reported	EE	NA	Restored	Herbaceous	Abundance	Bumblebees
	Germany							Wild bees
	Netherlands							
	Sweden							
Williams <i>et al.</i> (2015)	USA	Not reported	EE	NA	Restored	Herbaceous	Richness	Wild bees
Morandin <i>et al.</i> (2016)	USA	Tomato	II	10–100–200	Unrestored	Shrubs	Visit rate	Honeybees
Sardiñas <i>et al.</i> (2016)	USA	Sunflower	EE	NA	Unrestored	Shrubs	Abundance	Wild bees Wild bees
Balzan (2017)	Malta	Tomato	II	50–100–150–200*	Restored	Herbaceous	Abundance Yield	Wild bees
Campbell <i>et al.</i> (2017)	England	Apple	EE	NA	Restored	Herbaceous	Abundance	Bumblebees
							Richness Yield	Wild bees Wild pollinators
Caudill <i>et al.</i> (2017)	Costa Rica	Coffee	EI	50–150*	Unrestored	Arboreal	Abundance	Honeybees
							Richness Visit rate	Wild bees
Garratt <i>et al.</i> (2017)	England	Wheat	EE	NA	Unrestored	Arboreal	Abundance	Bumblebees
Dainese <i>et al.</i> (2017)	Italy	Wheat	EE	NA	Unrestored	Arboreal	Abundance	Butterflies
McKechnie <i>et al.</i> (2017)	Canada	Blueberry	EE	NA	Unrestored	Arboreal	Visit rate	Wild bees Wild bees
Tangtorwongsakul <i>et al.</i> (2018)	Thailand	Mango	EI	NR	Unrestored	Arboreal	Abundance	Wild bees
Venturini <i>et al.</i> (2017)	USA	Blueberry	EE	NA	Restored	Herbaceous	Richness Visit rate	Wild bees
Amy <i>et al.</i> (2018)	Belgium	Wheat	EE	NA	Restored	Herbaceous	Yield Abundance	Hoverflies Wild bees
Buhk <i>et al.</i> (2018)	Germany	Cereals Maize	EE	NA	Restored	Herbaceous	Richness Abundance	Wild bees
Ganser <i>et al.</i> (2018)	Switzerland	Strawberry	EI	80	Restored	Herbaceous	Abundance Richness Yield	Bumblebees Honeybees Hoverflies Wild bees
Pfiffner <i>et al.</i> (2018)	Switzerland	Cereals	EI	30	Restored	Herbaceous	Abundance	Wild bees

(continued)

Table 1. (continued)

Authors and Year	Country	Crops	Contrast	Survey distance within field (m)	Edge management	Edge type	Response variable	Pollinators
Rundlöf <i>et al.</i> (2018)	Sweden	Red clover	EE	NA	Restored	Herbaceous	Richness	Bumblebees
			EI	Between 8 and 100			Abundance	
			II	Between 8 and 100			Richness	
Wood <i>et al.</i> (2018)	USA	Cherry	EE	NA	Restored	Herbaceous	Abundance	Wild bees
		Blueberry	II	100			Richness	
Knapp <i>et al.</i> (2019)	England	Courgette	EI	25	Unrestored	Herbaceous	Abundance	Bumblebees Honeybees Hoverflies Wild bees

The descriptions EE: edge-edge, EI: edge-interior and II: interior-interior are indicated for the contrast in pollinator survey. For survey distance within field, descriptions are indicated NA: Not applicable; NR: Not reported; asterisk indicates studies where maximum survey distance selection was made.

Analyses were run independently for each type of contrast (i.e. edge-edge, edge-interior and interior-interior) and the effect size was estimated for the different levels within each moderator. The models were adjusted using the estimate of maximum restricted likelihood (Koricheva *et al.*, 2013).

Omnibus (*QM*) tests of individual moderators were performed to determine the heterogeneity of the effect sizes between the levels of each moderator (e.g. edge management levels). Furthermore, to explore the possibility of publication bias, funnel plots (scatter plots of effect sizes against a measure of their variance) were constructed to determine whether the reported studies were unbalanced (Koricheva *et al.*, 2013). A publication bias towards significant results would create an asymmetric funnel, which generally lacks small studies with no significant effects. In addition, a rank correlation test for funnel plot asymmetry was applied to examine whether the observed results and corresponding sampling variations were correlated (Begg & Mazumdar, 1994). A high correlation would indicate that the funnel chart is asymmetric, which would indicate a publication bias. All analyses and graphs were performed with the metafor package (Viechtbauer, 2010) through R version 3.4.4 (R Development Core Team, 2018).

Results

A total of 40 articles fulfilled our inclusion criteria (Table 1). From those, 137 effect sizes were obtained, which were distributed in 71 for the EE, 39 for EI and 27 for II contrasts. All studies were conducted in the northern hemisphere, with USA and England (12 studies each) being the main countries that have evaluated the questions associated with the conditions proposed in this meta-analysis. These studies were carried out between the years 1996 and 2019, most of them in the last decade, and were performed in 24 types of crops, more frequently in wheat (*Triticum aestivum* L.) and flowering crops such as blueberries (*Vaccinium angustifolium* Ait.), oilseed rape (*Brassica napus* L.) and tomatoes (*Solanum lycopersicum* L.) (Table 1).

Only in the EE contrast, there was a clear overall positive estimated effect size of field margin floral enhancements for both

abundance and richness of pollinators (Fig. 2). In this contrast, both for abundance and richness the heterogeneity test indicates differences between the levels of each proposed moderator (Table 2). The abundance of pollinators is the response variable with the highest number of cases of this entire review ($n = 40$). Restored edges and with the presence of herbaceous plants are those that present the greatest abundance and richness of pollinators on the edge, mainly for hoverflies (abundance-richness) and wild bees (richness). The estimated effect size for both EI and II contrasts is not significant for the set of evaluated moderators (Fig. 2). However, it is worth noting that in the EI contrast, we observe consistent positive effect sizes for pollinator abundance where field margin floral enhancements is restored with herbaceous plants, and for pollinator richness for both restored and unrestored sites, for arboreal and herbaceous edges, and for wild bees (Fig. 2).

The response in pollinator visitation rate did not have an adequate number of cases to perform an analysis for each moderator in each contrast, so only the type of contrast was used as a moderator in the estimation of the effect size. None of the contrasts present significant effect sizes (EE: $d = -0.58$; 95% CI = $-2.19, 1.02$; $P = 0.47$; $n = 4$;; EI: $d = 0.77$; 95% CI = $-0.37, 1.92$; $P = 0.18$; $n = 6$; and II: $d = 0.43$; 95% CI = $-0.65, 1.51$; $P = 0.43$; $n = 8$). Crop yield had only eight cases, which had a restored edge management with herbaceous plants, not having a significant effect size ($d = 0.46$; 95% CI = $-0.06, 0.99$; $P = 0.08$).

Publication bias inferred through funnel plot only shows asymmetry in effect sizes for both abundance and richness in the EE contrast (Fig. 3a,d). This coincides with the significant associations of the test of rank correlation. This indicates a bias in publications primarily with positive effect sizes and larger standard errors (i.e. low sample size) in this contrast; however, the strong positive response of the visiting pollinators at the crop edge could also be causing an asymmetry in the analysis.

Discussion

Studies on the effect of field margin floral enhancements on pollinators have focused primarily on assessing the diversity of

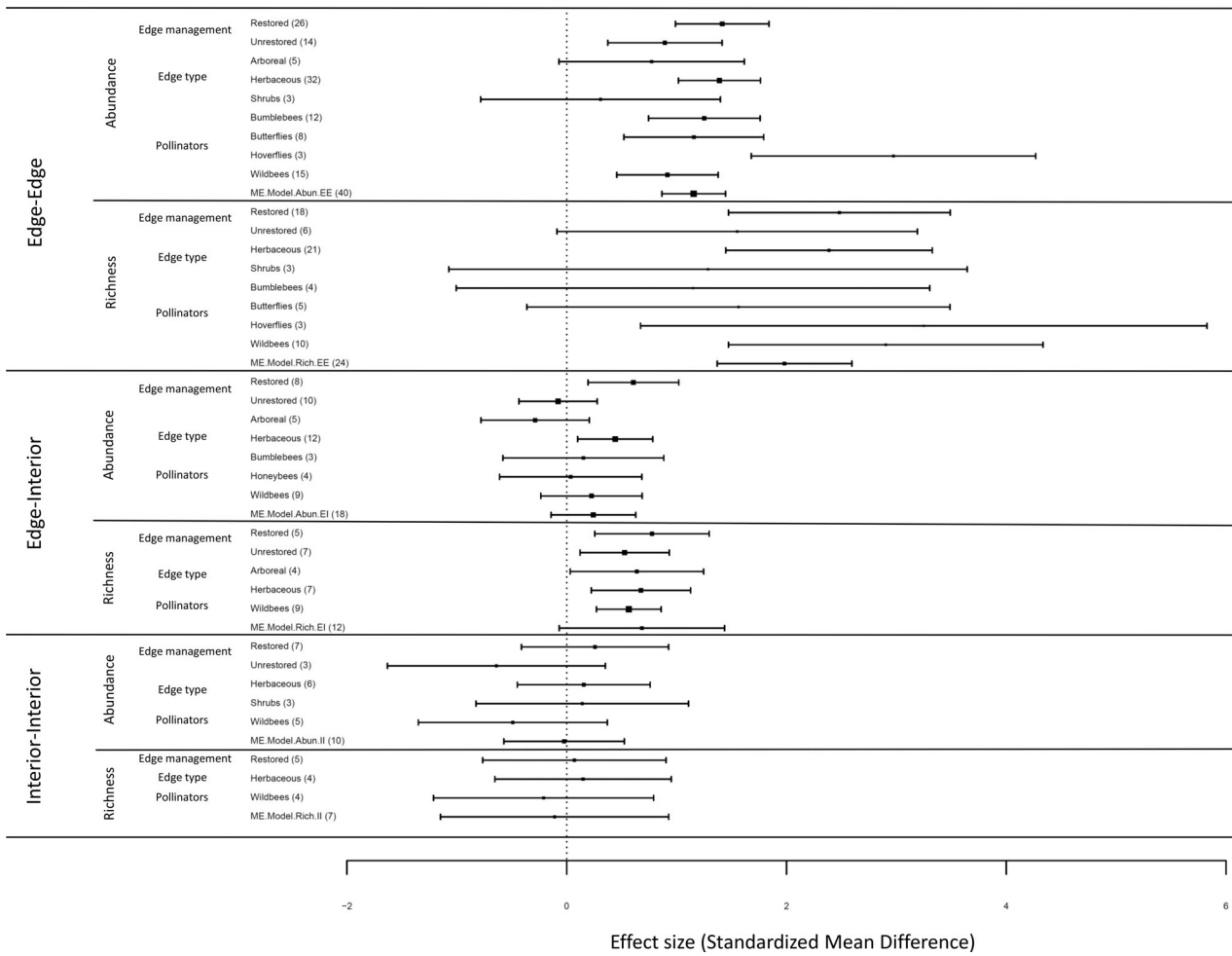


Figure 2. Effect of field margin floral enhancements on the abundance and richness of pollinators response in the edge–edge, edge–interior and interior–interior contrasts. Forest plot shows the effect size (Hedge’s *d*) and an estimated 95% CI of a mixed effects model for each moderator and the mean effect size for all moderators for pollinators abundance and richness in each contrast. The number of cases for the levels of each moderator is indicated in parentheses.

Table 2. Omnibus test for heterogeneity of moderators of effect sizes for the different levels in each contrast.

Contrast	Moderators	Abundance			Richness		
		df	<i>QM</i>	<i>P</i>	df	<i>QM</i>	<i>P</i>
Edge-Edge	Edge management	2	53.77	<0.0001	2	26.67	<0.0001
	Edge type	3	56.79	<0.0001	2	25.91	<0.0001
	Pollinators	6	80.32	<0.0001	5	26.93	<0.0001
Edge-Interior	Edge management	2	8.47	0.0145	2	15.02	0.0005
	Edge type	3	8.13	0.0432	3	13.09	0.004
	Pollinators	4	3.67	0.452	3	26.04	<0.0001
Interior-Interior	Edge management	2	2.17	0.337	2	0.52	0.77
	Edge type	3	5.11	0.163	3	2.04	0.563
	Pollinators	5	4.65	0.459	3	1.05	0.787

pollinators at the edge, and fewer efforts have been done trying to understand how these management tools affect pollinators within the field and ultimately, crop yield. Studies with edge–

edge contrast sought mainly to determine the ability of edge vegetation to generate resources for visiting pollinators, e.g. in bees, these translate into food and nesting sites (Kremen *et al.*, 2004).

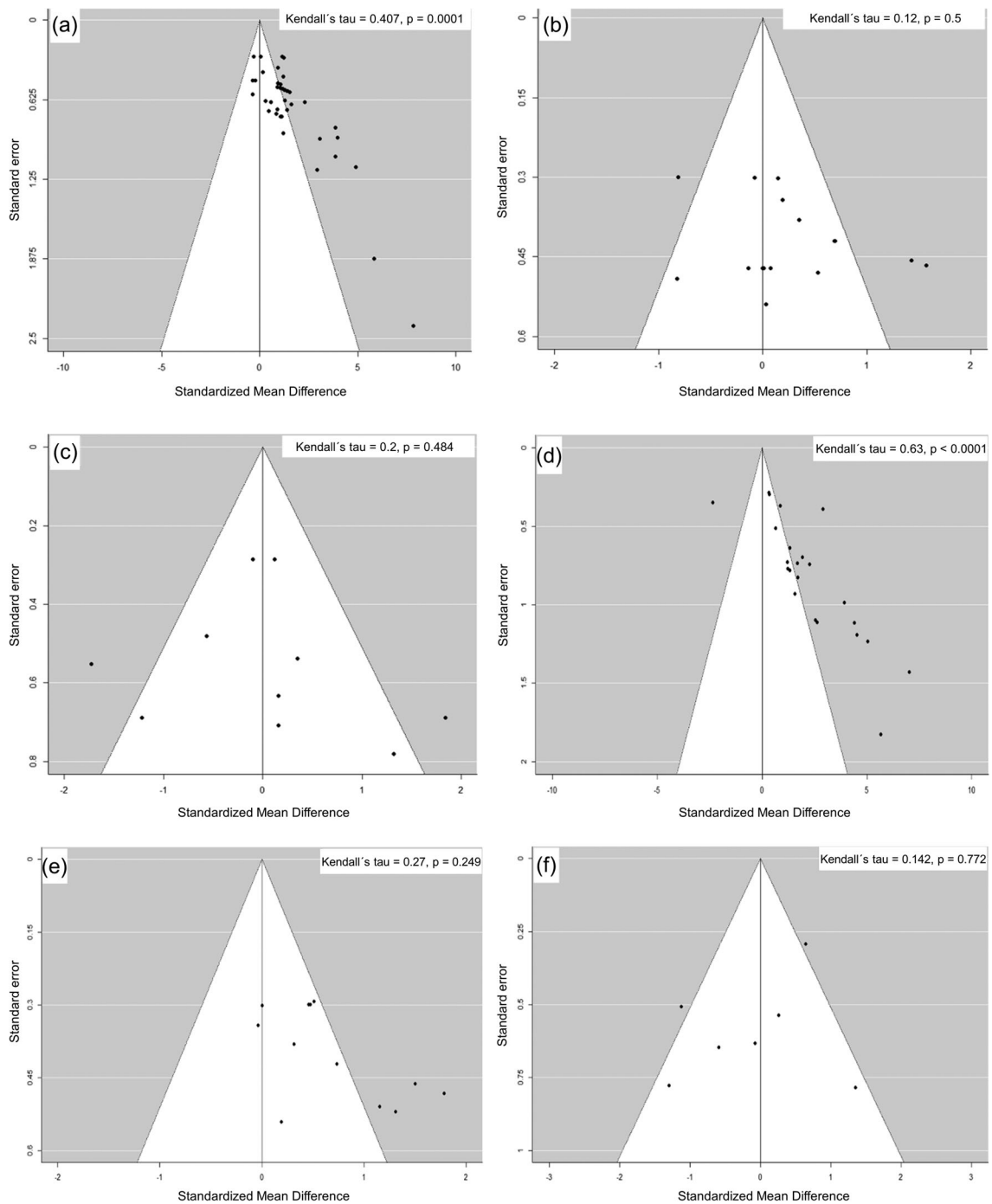


Figure 3. Funnel plot of the individual studies grouped by a: edge–edge abundance; b: edge–interior abundance; c: interior–interior abundance; d: edge–edge richness; e: edge–interior richness; F: interior–interior richness. Results for rank correlation test for funnel plot asymmetry are reported.

This evaluation does not allow to identify the possible spillover of insects from the edge towards the interior of the field. It only allows to determine whether this vegetation works as a conservation tool due to the attraction and permanence of potential pollinators at the edges of the field (Kremen *et al.*, 2019).

In this review, it was observed that the edge management tools that caused an increase in the abundance and richness of pollinators correspond to the management with restored edges and herbaceous plants, particularly in the case of hoverflies and wild bees. This is in agreement with studies that have also shown that

peripheral areas around crops that contain varied species of wild flowers have positive effects on the abundance and diversity of many insect pollinators, such as honeybees, bumblebees, butterflies, hoverflies and other diptera insects (Lagerlöf *et al.*, 1992; Carreck & Williams, 1997; Cheesman, 1998; Bäckman & Tiainen, 2002; Croxton *et al.*, 2005), mainly associated herbaceous plants (Prys-Jones & Corbet, 1991; Fussell & Corbet, 1992; Mader *et al.*, 2011) and restored edges (Morandin *et al.*, 2016; Kremen *et al.*, 2019). These edge management techniques are associated with an increase in floral diversity generating an increase in the supply of resources for pollinators, potentially allowing an increase in pollinators in the area (Carvell *et al.*, 2004; Pywell *et al.*, 2005; Greenleaf & Kremen, 2006; Winfree *et al.*, 2008).

Two hypotheses have been proposed regarding the effect of field margin floral enhancements (e.g., hedgerows) on the pollinator communities visiting the crops (Kremen *et al.*, 2019). On the one hand, we can expect an ‘exporter’ effect (i.e., spillover) of pollinators from the edge into the crop (Morandin & Kremen, 2013b; M’Gonigle *et al.*, 2015), and on the other hand, a pollinator ‘concentrator’ effect on the edge (i.e., pollinators are concentrated in the crop edges with greater foraging resources) (Kleijn *et al.*, 2018; Kremen *et al.*, 2019). This contrasting hypothesis may explain the positive and negative effects documented in the analysis of pollinators visiting the crop. In the case of studies with edge–interior contrast, where the comparison was made between the edge and the interior of the same field (i.e., interior as the control), there is a positive effect for several levels of the moderators mainly on the pollinator richness responses (i.e., greater richness in the edge). This would be giving account of a possible pollinator concentrating effect in these studies, i.e., there is an absence of spillover, so that the field margin floral enhancements would work only as a pollinator conservation tool at the field edge (Kremen *et al.*, 2019). Although this evaluation could show a possible ‘concentrator’ effect of pollinators, it is necessary to directly elucidate the absence of spillover (e.g. with insect marking), since it is possible that a change in abundance and richness within the field could be both independent as parallel to the changes in the edge, after the field margin floral enhancements.

In the case of the interior–interior design, it is the one that would specifically determine the effect of the edge enhancement on the diversity of pollinators within the field (Morandin *et al.*, 2016). For this contrast, the results indicate that there is heterogeneity in responses when comparing sites with and without field margin floral enhancements, although the number of cases for this contrast is low. Overall, our results suggest a possible neutral effect of field margin floral enhancements on the pollination service in the crops included in this review, consistent with the idea that the edges would be functioning as pollinator attractors and concentrators, but not demonstrating the spillover towards the crop and the consequent ecosystem service delivery (Sardiñas & Kremen, 2015; Sardiñas *et al.*, 2016; Dainese *et al.*, 2017). However, it is important to consider that the effect of field margin floral enhancements on pollinators within the crop may require time, as pollinator populations fluctuate from year to year and it could take time for them to colonise new habitats and build up larger population sizes (Williams *et al.*, 2001). For example, Blaauw and Isaacs (2014) observed

that in wild bees and hoverflies the visitation rate of these began to increase within the crop after the third year of the field margin floral enhancements, so that these populations would be depending on the abundance of the vegetation of previous years. The reviewed papers generally test edges with less than 3 years, opening the door to find more consistent effects when analysed over longer time periods. On the other hand, several edge–interior and interior–interior studies present different sampling distances towards the interior of the field and in three of them we apply maximum survey distance selection (Table 1); however, in these last studies, the sampling sites in the interior of the crop, there are no significant differences in the visit of pollinators (Morandin & Kremen, 2013a,b; Sardiñas *et al.*, 2016; Caudill *et al.*, 2017), so the response is constant within the crop. Therefore, we consider that, despite this variability of sampling distances within the fields, the results allow us to determine a no consistent pollinator spillover to crops.

The results for crop yield have no effect in the eight cases included, which is consistent with some of the studies analysed in the review by Kremen *et al.* (2019) and with the results by Albrecht *et al.* (2020), but opposed to studies conducted in oil-seed rape where pollinator diversity and crop yield increase, the latter due to the interaction between semi-natural landscapes with the effect of the edge vegetation (Haenke *et al.*, 2014; Sutter *et al.*, 2018). It is possible that a set of other factors, such as the type of crop, the composition and heterogeneity of the surrounding landscapes, the size of the edges and their distance towards the interior of the fields, could be affecting the relationship between edge management, pollinators and yield. Albrecht *et al.* (2020) determined in a synthesis, results similar to those of this study, where they found that the pollination service increases in sites with enhanced field margins, but this effect only occurs adjacent to the edge and with the absence of effect on crop yield. This could be due to different crop management practices (Bartomeus *et al.*, 2015; Gagic *et al.*, 2017) in addition to the landscape context (Dainese *et al.*, 2017), which would be generating variability in the responses of crop production. Further studies need to isolate these factors to understand the effects of edge management on crop yield (Mwangi *et al.*, 2012; Sardiñas & Kremen, 2015; Morandin *et al.*, 2016).

An important finding of our review is that most of the identified studies have been conducted almost exclusively in the northern hemisphere, with greater prominence of USA and Europe. This result stress the importance of expanding efforts to other regions where to implement and evaluate these tools of biodiversity management and where information on these forms of crop management is still lacking. The situation elsewhere is different from the European context where the application of agri-environmental schemes has made a greater progress in the use of these management tools.

In summary, there is a set of gaps in the knowledge about the use of field margin floral enhancements as a biodiversity management tool in agroecosystems, with most studies evaluating the use of these tools with pollinator conservation purposes in mind, but very few studies addressing pollination services delivered and yield. Under the current global decline in pollinator populations, it is urgent to advance in the understanding and identification of the factors that modulate the relationship

between the management of crop edges and pollinators in order to enhance their conservation and ecosystem services in productive environments.

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Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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