





Article

The Attractiveness of Five Common Mediterranean Weeds to Pollinators

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Abstract: Concerns about a global decline in pollinators have called for more knowledge about the factors influencing wild pollinator abundance and diversity in agroecosystems. Agricultural intensification has been identified as the main cause of this “global pollinator crisis”, particularly due to reductions in natural areas holding critical floral and nesting resources. Maintaining native wild plants in agricultural landscapes (e.g., in field margins) is often recommended as a cost-effective and efficient method for pollinator conservation. In this study, the role of common wild flowers, often considered weeds, in supporting pollinators in a Mediterranean agroecosystem was investigated. This work involved a two-year field trial to compare five native weed species common in Mediterranean cereal agroecosystems: *Convolvulus arvensis* L., *Daucus carota* L., *Malva sylvestris* L., *Papaver rhoeas* L., and *Sonchus oleraceus* L. The goal was to compare the attractiveness of these species, and a mixture of all five, to different flower-visiting insect groups in order to assess their value in supporting wild pollinators. Overall, *D. carota* had the highest number of insect visits, followed by *P. rhoeas*. *C. arvensis*, *M. sylvestris*, and *S. oleraceus*, which had lower numbers of visits. On the basis of their overall attractiveness to pollinators and low risk for invasiveness, *D. carota*, *P. rhoeas*, and *M. sylvestris* are the most likely to contribute positively to the conservation of pollinators in agroecosystems. Our results also suggest that it is advantageous for wild flowers sown for the purpose of pollinator conservation to be grown in clumps, rather than highly intermingled, for improved visitation rates.

Keywords: agroecosystems; biodiversity; ecosystem services; field margins; environmental management; pollinator conservation; sustainable agriculture; weed science



Citation: Morrison, J.; Izquierdo, J.; Hernández Plaza, E.; González-Andújar, J.L. The Attractiveness of Five Common Mediterranean Weeds to Pollinators. *Agronomy* **2021**, *11*, 1314. <https://doi.org/10.3390/agronomy11071314>

Received: 17 May 2021
Accepted: 23 June 2021
Published: 28 June 2021

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1. Introduction

In recent years, increasingly intensive agricultural practices have resulted in great concerns about a potential global decline in pollinators, both in terms of species richness and abundance [1]. Maintaining a diverse and abundant community of effective pollinators is crucial for sustaining native plant species diversity and the efficiency and stability of agricultural production [2]. The effects of the global decline in pollinators have already begun to be documented: a lower plant growth rate has been detected in highly pollinator-dependent crops compared to non- or low-dependent crops [3].

The transformation of agricultural landscapes in the past half-century that has triggered this decline in bees and other pollinators [3] has involved the conversion of forests into fields and pastures [4], the expansion and amalgamation of pre-existing fields in order to enhance farming efficiency [5], and increased input of agricultural pesticides [6]. These changes have resulted in more homogeneous landscapes with a greater fragmentation of natural habitats. Agricultural pesticides negatively impact pollinator populations by further reducing foraging and habitat diversity, and they may have toxic effects [7].

Homogeneous landscapes can be enriched by encouraging the presence of native wild plant species [5]. Retaining a diversity of native wild flowers in agroecosystems is considered to be one strategy for curtailing the global decline of pollinators, as they are important hosts, providing continuous nesting and floral resources [8]. A diversity of wild flowers provides pollinators with a stable supply of pollen, nectar, and floral oils, notably when the main crop is not in bloom [9]. Because different insect species have different floral preferences, a season-long, high diversity of flowering plant species is required to support a high diversity of native pollinator species [3]. More detailed quantification of the role of native wild flowers in attracting pollinators could help enforce a new paradigm for agricultural management and biodiversity conservation.

Among the large number of species known as wild flowers, there is a specific set that is considered “weeds” by farmers—that is, species that tend to appear within fields provoking crop yield losses. These particular wild flowers have the reputation of being destructive in agriculture, and research typically focuses on the negative impacts of weeds and approaches to limit these impacts [10]. However, weeds are becoming more appreciated for their significant role in supporting biodiversity and ecosystem services [10,11]. Managing weeds with the specific goal of enhancing wild pollinator populations is currently largely based only on educated guesswork [3].

The general objective of this work is to further understand the role of weeds in agroecosystems and how they support pollinator abundance and diversity. To achieve this, five weed species common in Mediterranean agroecosystems with known attractiveness to wild pollinators were compared on the basis of the foraging rates of flower visiting insects. The selected species were: *Convolvulus arvensis* L. (commonly known as field bindweed), *Daucus carota* L. (wild carrot or, in North America, Queen Anne’s lace), *Malva sylvestris* L. (common mallow), *Papaver rhoeas* L. (common poppy or corn poppy), and *Sonchus oleraceus* L. (common sow thistle or annual sow thistle). These plant species are typically considered weeds, found frequently near cereal crops in the Iberian peninsula [12]. In this study, we examined the potential of each of these species and a mixture of all species to support pollinators by assessing: (a) the potential of each flower treatment to attract pollinators, (b) differences between treatments in terms of total pollinator visits, (c) differences between treatments in terms of their attraction to different taxonomic pollinator groups, and (d) whether flower species had more visits when grown in monocultures or mixed stands.

2. Materials and Methods

2.1. Study Site and Experimental Design

This experiment was carried out over two years, 2015 and 2016, at Agropolis, the research station of the School of Agriculture of the Universitat Politècnica de Catalunya. Agropolis is located in Viladecans (41°17'24" N 2°02'43" E, 0 m.a.s.l.) in a flat, highly agricultural area. The mean monthly temperature was 16.7 °C in 2015 and 16.8 °C in 2016. The total rainfall was 376 mm in 2015 and 456 mm in 2016 [13]. The landscape in a 1-km radius surrounding the experimental site was 45% arable lands and orchards, 20% pasture, and 35% urban and unproductive lands [14].

The experimental area comprised three blocks with a 2-m space between them. In each block were six plots (2.5 m × 2.5 m) with a 1.5-m space between them. Five plots were planted with a different species in monoculture and one plot was planted with a mixture of all five species randomly and equally distributed throughout the plot. The plots within each block were organized randomly such that each arrangement was unique and no two similar plots were located adjacent to one another.

2.2. Weed Species Selection and Plot Preparation

C. arvensis, *D. carota*, *M. sylvestris*, *P. rhoeas*, and *S. oleraceus* were selected based on observations carried out in a previous study [15] on the foraging activity of flower visiting insects in cereal field margins in Catalonia. These five weed species were selected because they had the highest bee visits to plant occurrence ratios.

In preparation for the first year of sampling, the seeds of the selected species were sown in a greenhouse in early 2015. When ready, seedlings were transplanted at the experimental site. For *S. oleraceus*, *D. carota*, and *P. rhoeas*, 64 plants were planted per plot (eight rows of eight plants). For *M. sylvestris*, only 32 plants were planted per plot (four rows of four plants) because of the large canopy and numerous flowers of each individual plant. *C. arvensis* was already an abundant species in this field and grew naturally in its designated plots. Mixed plots were made up of 13 plants of *S. oleraceus*, *D. carota*, and *P. rhoeas*; 6 plants of *M. sylvestris*; and approximately 20% of the plot was left with *C. arvensis*. A second round of transplanting replaced any seedlings that did not survive to maturity. At the end of the first season, the plots of annuals (*S. oleraceus* and *P. rhoeas*) were tilled by hand in order to incorporate the seeds and establish plots for the upcoming year. Biennials and perennials (*D. carota* and *M. sylvestris*) were trimmed down and preserved for the following year. *C. arvensis* was a prevalent weed with no need for manipulation in order to ensure its presence in the following year. In early 2016, more seeds of all planted species were sown in the greenhouse and later transplanted in order to supplement what had regrown from the previous year, filling any holes in the coverage.

All attempts were made to establish an even coverage in each plot. Ultimately, the number of open flowers was considered in the data analysis; thus, variations in the exact number of plants were accounted for. During both years, the site was irrigated one to two times per week and all undesirable plant species were removed regularly. Borders and walkways were cut down and sprayed with herbicide (Glyphosate 36%) in order to avoid any external interference.

2.3. Sampling Insect Visits

Observations of insect visits to flowers were carried out twice a week on days when temperatures were at least 17 °C with no rain [16]. Observations were conducted in the morning, between 8 h and 12 h 30, when wind speed was at a minimum. For each plot, the sampling season began when there were at least five open flowers. For the mixed plots, sampling began when there were at least two species with five or more open flowers. Likewise, the sampling season ended when there were less than five open flowers per plot or, for the mixed plots, less than two species with five or more open flowers.

Sampling methodology was based on that of Barbir et al. [17]. On sampling days, the order in which the blocks were sampled alternated systematically. In each plot, first, the number of open flowers was counted. For *D. carota*, each inflorescence was considered one floral unit. Next, during a five minute period per plot, all insect visits were recorded in which the insect made direct contact with the reproductive organs of a flower (i.e., stamens and pistils). Insects were divided into the following groups: bees (order: Hymenoptera, clade: Anthophila), beetles (order: Coleoptera), hoverflies (order: Diptera, family: Syrphidae), butterflies and moths (order: Lepidoptera), true bugs (order: Hemiptera, suborder: Heteroptera), wasps (order: Hymenoptera, suborder: Apocrita), and other insects.

2.4. Data Analysis

At the end of each sampling season, the length of the flowering period, the average number of flowers, and the average number of insect visits were obtained for each plot. The flowering period was calculated as the number of days in which more than five flowers were in bloom in a single plot. The average number of flowers was obtained by dividing the total number of flowers recorded in each plot throughout the sampling season by the number of sampling days.

$$\text{Average number of flowers} = \frac{\sum_{\text{plot}}^{\text{days}} \text{number of flowers}}{\text{number of sampling days}}$$

The average number of insect visits was obtained by calculating the total number of insect visits recorded during the 5 min periods of each observation day for each plot during the sampling season, divided by the number of sampling days.

$$\text{Average number of insect visits} = \frac{\sum_{\text{plot}}^{\text{days}} \text{number of insect visits recorded}}{\text{number of sampling days}}$$

We obtained both an average of all visiting insects (all taxonomic groups combined), as well as an average for bees only, beetles only, and all other insects groups combined (due to their overall low number of visits). In addition, in the mixed plots, the average number of insect visits and the average number of flowers were also obtained separately for each of the flower species. All analyses were carried out in R 3.6.3 for Linux [18].

2.4.1. Potential of Flower Treatment to Attract Pollinators

Differences between treatments (all species in monoculture and the mixed plots) in the length of the flowering period and the average number of flowers were analyzed using general mixed-effects models using functions from the package lme4 [19]. Treatment, year, and their interaction were included as fixed factors, and the block was included as a random factor. Although we were interested in the main effect of flower treatment, an interaction term with the year was included because inter-annual variation in precipitation and temperature in Mediterranean climates can largely determine the response of vegetation and the associated taxa. Additionally, we preferred to include the year as a fixed factor and not as a random factor because having a random factor with only two levels (two years) can lead to problems in the model (lack of model convergence in our case). The overall importance of fixed effects was assessed by a type III Wald test using a chi-square statistic in the library package car [20]. Marginal and conditional R^2 were computed using functions from the MuMIn library [21] to obtain the variability explained by the fixed factors and the whole model, respectively [22]. Model assumptions were graphically assessed using functions from the package ggResidpanel [23]. Post hoc comparisons were computed using functions from the emmeans package [24].

2.4.2. Insect Visits to Flower Treatments

Total Pollinator Visits

Differences between treatments in the average number of pollinator visits (all insect groups combined) were analyzed using general linear mixed models as explained above. Treatment, year, and their interaction were included as fixed effects. The average number of flowers for each plot was also included as a covariate to account for differences between plots in terms of the availability of flowers for insects to visit. Block was included as a random factor.

Visits by Taxonomic Group

A general mixed-effects model was also used to analyze whether treatments differed in their attraction to the pollinator groups (bees, beetles, and the rest of the groups together) following the procedure described above. The model was similar to the one used to analyze the total number of pollinator visits, but in this case, the taxonomic group and its interaction with the treatment and the triple interaction between the year, treatment, and taxonomic group were also included as a fixed factors.

Pollinator Visits to Flowers Growing in Monocultures vs. Flowers Growing in Mixed Treatments

Finally, we also tested whether flower species had more visits when growing in monocultures or mixed stands. To accomplish this, we first obtained the average number of insect visits in the mixed plots separately for each flower species. Then, a general mixed-effects model was used with the flower treatment, growing treatment (monoculture

vs. mixed stands), year, and the interactions between the growing treatment and flower treatment as well as the growing treatment and year as fixed factors. The average number of flowers was also included as a covariate. In this case, the number of flowers in the mixed plots was computed separately for each flower species. Block was included as a random factor.

3. Results

3.1. Insect Visits to the Experimental Site

In total, 4770 insects were observed foraging on experimental flowers in 2015, and 4289 insects were observed in 2016 (Figure 1). In 2015, the greatest number of observed visits was by bees (2913 visits), then beetles (1110), hoverflies (435), true bugs (115), other insects (78), butterflies and moths (63), and wasps (56). In 2016, the most frequently observed flower visitors were beetles (2172 visits), then bees (1194), true bugs (788), other insects (96), hoverflies (16), wasps (14), and butterflies and moths (9).

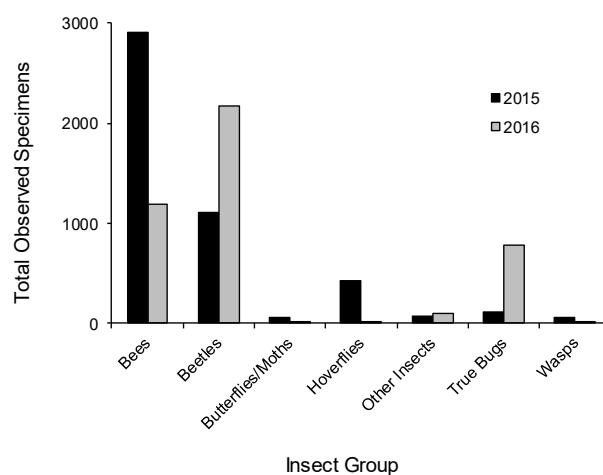


Figure 1. Total observed specimens of each insect group per year.

Of the true bugs observed, in 2015, 65% were *Oxycarenus lavaterae* (family: Lygaeidae), 32% were larger true bugs from the families Lygaeidae or Pyrrhocoridae, likely *Lygaeus equestris* or *Scantius aegyptius*, and 3% were other species. In 2016, 96% were *O. lavaterae* and 4% were from the families Lygaeidae or Pyrrhocoridae. (Refer to Supplemental Material, Section 1.1, for more details about insect identification using pan traps.)

3.2. Potential of Flower Treatment to Attract Pollinators

Flower species varied in the length of the flowering period and the average number of flowers, but the differences depended on the year (as shown by year and treatment interactions; flowering period: chi-square = 67.8, df = 5, $p < 0.001$; number of flowers: chi-square = 18.7, df = 5, $p = 0.002$; Supplemental Material—Tables S1 and S2). Regarding the flowering period, the interaction was mainly driven by an increase in the length of the flowering period in *M. sylvestris* and *S. oleraceus* plots in 2016 with respect to 2015. In both years, *C. arvensis* and mixed plots had the longest flowering periods, whereas *S. oleraceus* and *P. rhoeas* plots had the shortest. *M. sylvestris* and *D. carota* plots had flowering periods of intermediate length (Figure 2). As for the number of flowers, the interaction was mostly due to an increase in the values for *M. sylvestris* plots and a decrease in *P. rhoeas* plots in 2016 with respect to 2015. In 2015, *C. arvensis* and *D. carota* plots had the highest number of flowers and *M. sylvestris* and *S. oleraceus* plots had the lowest, whereas *P. rhoeas* and mixed plots were intermediate in their values. In 2016, *C. arvensis* had the highest number of flowers, *P. rhoeas* and *S. oleraceus* the lowest, and the rest of the flower treatments had intermediate values (Figure 3). Fixed factors in the models accounted for 94% and 61% of the variability encountered in the length of the flowering period and the

number of flowers, respectively (R^2 marginal). Block explained an additional 5% of the variability for the number of flowers but had a negligible effect on the flowering period (R^2 conditional— R^2 marginal).

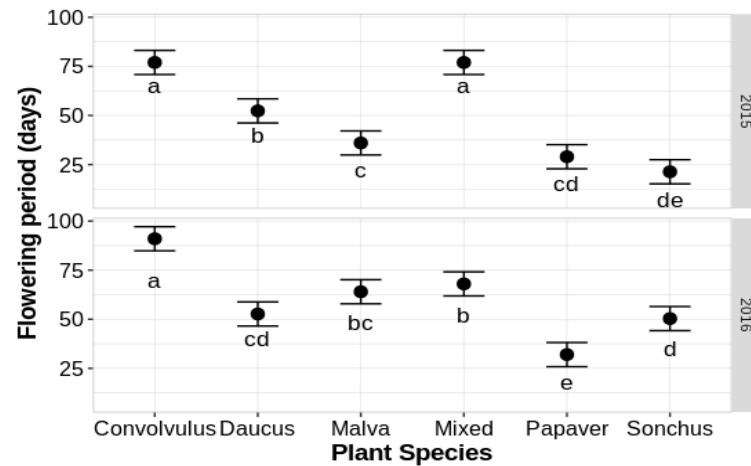


Figure 2. Differences in the lengths of the flowering periods between flower treatments in both years of the study (2015 and 2016). Values are the estimated marginal means from the general mixed-effects model. Bars show confidence intervals at the 0.95 level. Letters indicate differences between treatments derived from post hoc pairwise comparisons using the Tukey method for p -value adjustment. Contrasts were performed between treatments and for each year separately. Flower species are indicated by genus.

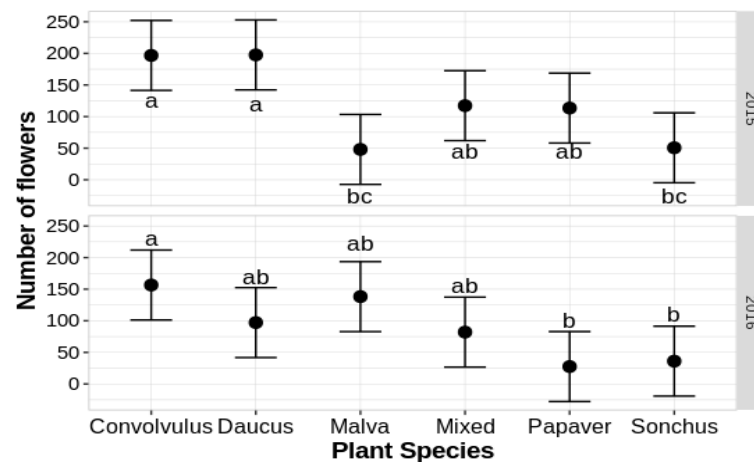


Figure 3. Differences between treatments in the average number of flowers in both years of the study (2015 and 2016). Values are the estimated marginal means from the general mixed-effects model. Bars show confidence intervals at the 0.95 level. Letters indicate differences between treatments derived from post hoc pairwise comparisons using the Tukey method for p -value adjustment. Contrasts were performed between treatments and for each year separately. Flower species are indicated by genus.

3.3. Insect Visits to Flower Treatments

3.3.1. Total Pollinator Visits

Treatments differed in the average number of insect visits, and the effect was dependent on the year (year \times treatment interaction: chi-square = 73.1, $df = 5$, $p < 0.001$; Table 1, Figure 4). The interaction was due to a decrease in the number of visits recorded in *P. rhoeas* plots in 2016. Overall, across both years, *D. carota* plots had the highest number of insect visits, followed by *P. rhoeas* and then mixed plots. *C. arvensis*, *M. sylvestris*, and *S. oleraceus* had lower numbers of visits. In 2015, *P. rhoeas* plots had a number of visits similar to that of *D. carota* plots, but in 2016, the average number of visits recorded in the *P. rhoeas*

treatment was much lower and similar to the other treatments. The model also showed a slight positive effect of the number of flowers on the visitation of insects to the plots (number of flowers = 0.027 ± 0.016 ; chi-square = 2.9, $df = 1$, $p = 0.09$; Table 1). Fixed factors in the model accounted for 94% of the variability encountered in the response variable (R^2 marginal), with block explaining less than 1% of the variability.

Table 1. Effects of flower treatment, year, their interaction, and the average number of flowers on the average number of pollinator visits to the plots. Chi-square values and degrees of freedom (df) were derived via a general linear mixed model.

| | Chi-Square | df | <i>p</i> |
|-------------------------|------------|----|----------|
| Intercept | 5.1 | 1 | <0.001 |
| Flower treatment | 233.8 | 5 | <0.001 |
| Year | 0.09 | 1 | 0.03 |
| Number of flowers | 2.91 | 1 | 0.09 |
| Treatment \times Year | 73.1 | 5 | <0.001 |

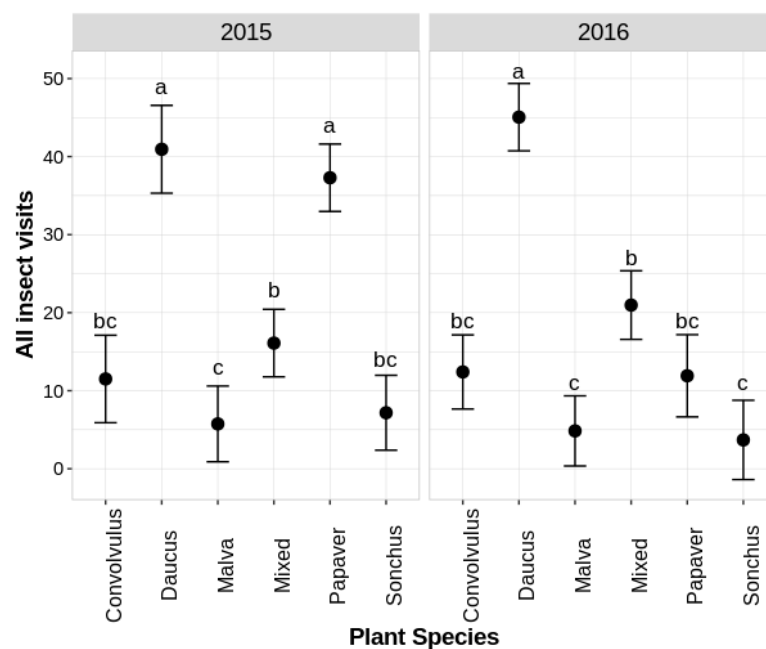


Figure 4. Differences in the average number of insect visits per five-minute period to the flower treatments in both years of the study (2015 and 2016). Values are the estimated marginal means from the general mixed-effects model accounting for the number of flowers in the plots. Bars show confidence intervals at the 0.95 level. Letters indicate differences between treatments derived from post hoc pairwise comparisons using the Tukey method for p -value adjustment (at $p < 0.05$). Contrasts were performed between treatments and for each year separately. Flower species are indicated by genus.

3.3.2. Visits by Taxonomic Group

Treatments differed in the number of visits received from bees, beetles, and the rest of the taxonomic groups, and this response was also affected by the year (treatment by taxonomic group by year interaction Table 2; Figure 5). To explore the significance of the interaction, we used Tukey's contrasts (a) between flower treatments within years and insect taxonomic groups and (b) between insect taxonomic groups within years and flower treatments. Contrasts between flower treatments showed the relevance of *D. carota* for all insect groups and *P. rhoeas* for bees (Figure 5). *P. rhoeas* and *D. carota* had a higher number of bee visits for both years, with the other flower treatments ranking slightly differently across the years. Regarding beetles, *D. carota* plots received a higher number of visits

than the other treatments in both years. For the other insect groups combined, *D. carota* in 2015, together with the mixed treatment in 2016, registered more visits than the other treatments. Additionally, contrasts between insect groups—within flower treatments and years—showed that in 2015, bees represented the majority of the insect visits to plots, except in the case of *D. carota* and *M. sylvestris* plots, which received a similar number of visits from the three insect groups. In 2016, beetles surpassed or equalled the number of bee visits in some treatments. *D. carota* plots had more visits by beetles than by the other two groups, *C. arvensis* plots had more visits from beetles and bees than from the other insect groups combined, and the mixed plots registered more visits from beetles and other insect groups than from bees. On the contrary, *M. sylvestris* and *S. oleraceus* had a low number of visits from all three insect groups, and *P. rhoeas* had more visits from bees. Fixed factors in the model accounted for 93% of the variability encountered in the response variable (R^2 marginal), with block explaining less than 1% of the variability.

Table 2. Effects of flower treatment, year, taxonomic group, their interactions, and the average number of flowers on the average number of pollinator visits to the plots. Chi-square values and degrees of freedom (df) were derived via a general linear mixed model.

| | Chi-Square | df | <i>p</i> |
|------------------------------------|------------|----|----------|
| Intercept | 17.8 | 1 | <0.001 |
| Flower treatment | 473.5 | 5 | <0.001 |
| Year | 4.24 | 1 | 0.04 |
| Number of flowers | 2.93 | 1 | 0.09 |
| Taxonomic group | 16.76 | 2 | <0.001 |
| Treatment × Year | 148.33 | 5 | <0.001 |
| Treatment × Taxonomic group | 344.5 | 10 | <0.001 |
| Year × Taxonomic group | 13.5 | 2 | 0.001 |
| Treatment × Year × Taxonomic group | 141.5 | 10 | <0.001 |

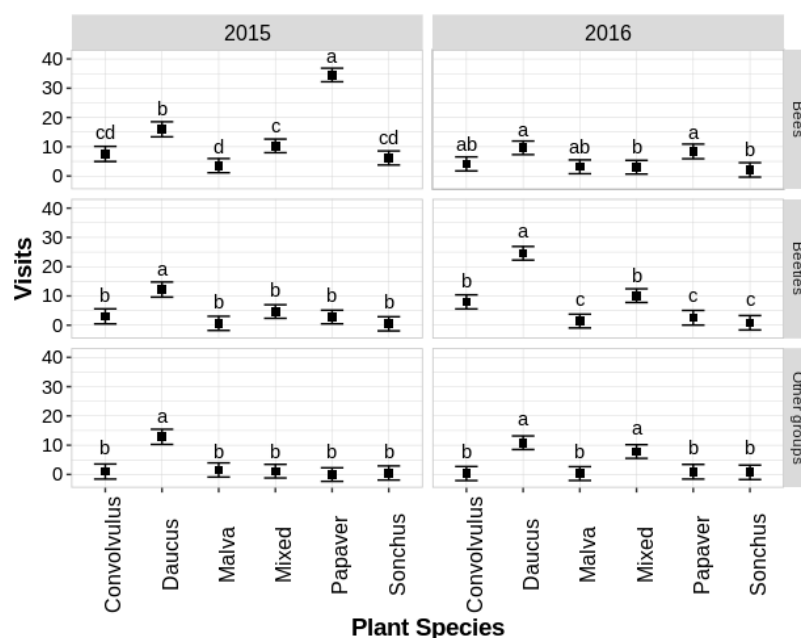


Figure 5. Differences in the average number of visits from bees, beetles, and other insect groups to the flower treatments in both years of the study (2015 and 2016). Values are the estimated marginal means from the general mixed-effects model accounting for the number of flowers in the plots. Bars show confidence intervals at the 0.95 level. Letters indicate differences between treatments for a given year and insect taxonomic group derived from post hoc pairwise comparisons using the Tukey method for *p*-value adjustment (at $p < 0.05$). Flower species are indicated by genus.

3.3.3. Pollinator Visits to Flowers Growing in Monocultures vs. Flowers Growing in Mixed Treatments

Flowers growing in monocultures received more visits than those growing in the mixed stands, but the difference depended on the flower species (as shown by growing treatment \times flower treatment: chi-square = 98.5, df = 4, $p < 0.001$; Table 3, Figure 6). Tukey contrasts, performed separately for each species, showed that for *S. oleraceus* and *M. sylvestris*, the number of visits was quite similar across growing treatments, whereas the other flower species received a higher number of visits in monoculture plots. This effect was similar across both years (growing treatment \times year: chi-square = 3.6, df = 1, $p = 0.06$; Table 3). A higher number of flowers was positively related to a higher number of insect visits (chi-square = 7.9, df = 1, $p = 0.005$; Table 3). Fixed factors in the model accounted for 89% of the variability encountered in the response variable (R^2 marginal), with block explaining less than 1% of the variability.

Table 3. Effects of growing treatment (monoculture vs. mixed), flower treatment, year, interactions between growing treatment and flower treatment as well as growing treatment and year, and the average number of flowers on the average number of pollinator visits to the plots. Chi-square values and degrees of freedom (df) were derived via a general linear mixed model.

| | Chi-Square | df | <i>p</i> |
|---|------------|----|----------|
| Intercept | 0.18 | 1 | 0.67 |
| Growing treatment | 7.3 | 1 | 0.007 |
| Flower treatment | 2.7 | 4 | 0.61 |
| Year | 0.02 | 1 | 0.89 |
| Number of flowers | 7.9 | 1 | 0.09 |
| Growing treatment \times Flower treatment | 98.5 | 4 | <0.001 |
| Growing treatment \times Year | 3.6 | 1 | 0.06 |

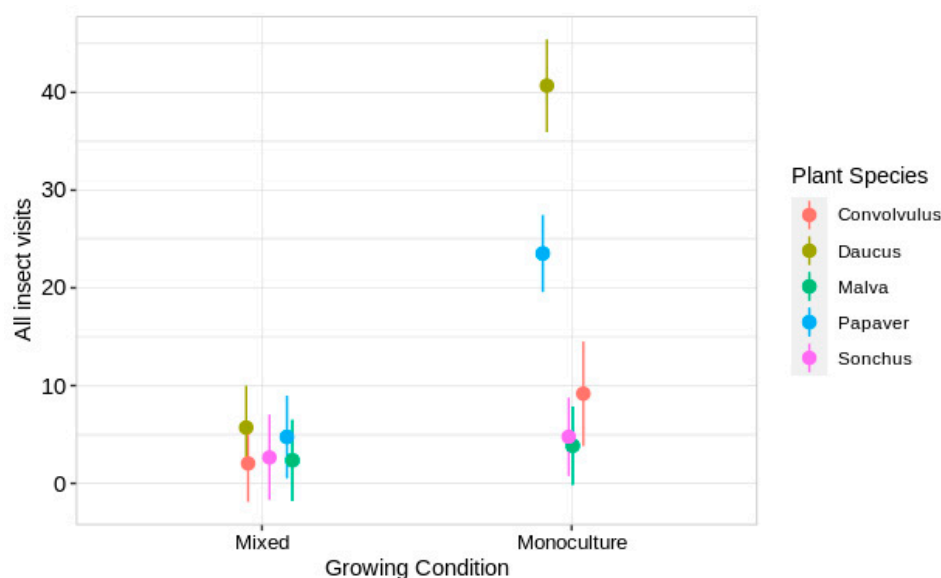


Figure 6. Differences in the average number of insect visits when plants were grown in monocultures vs. mixed plots. Values are the estimated marginal means from the general mixed-effects model accounting for the number of flowers in the plots. Bars show confidence intervals at the 0.95 level. Flower species are indicated by genus.

4. Discussion

4.1. Visits to Flower Species

In the following sections, we examine the potential of each flower species to support pollinators in agroecosystems.

4.1.1. *D. carota*

Relative to the other flowers, *D. carota* had a moderate flowering period and a high number of insect visits. There were many visits from bees and beetles to *D. carota*, as well as a relatively high number of visits from other groups of pollinators. *D. carota* was found to attract a great diversity of insect visitors, having visits from all insect groups in both years, except butterflies and moths. Our results are in agreement with several studies, which all observed a wide taxonomical range of insect visitors to *D. carota* [25–27].

The high number of insect visits to *D. carota* could be due to a number of reasons. First, unlike all the other species, the floral nectaries of *D. carota* are fully exposed [28], and the open accessible inflorescences facilitate contact from any suitably sized insect [29]. Westmoreland and Muntan [30] suggested that flies and beetles are attracted to the plant's slightly pungent scent. These factors may explain why *D. carota* had a high number of insect visits compared to the other species and a wide variety of visitors.

The seeds of *D. carota* can reportedly persist in the soil seed bank for two to five years [31], and seedlings can emerge and survive in several types of ground cover, including thick vegetation [32]. *D. carota* is not usually considered a high priority for management efforts. Nevertheless, it can be persistent and require more active management in soils with a high clay content [32]. Eckardt [32] also claimed that it is a threat to recovering grasslands and prairies because it matures faster and grows taller than many of the native species.

In summary, based on its overall attractiveness to a wide range of pollinators, non-priority status as a weed, and moderately long flowering period, *D. carota* is likely to contribute positively to pollinators in agroecosystems.

4.1.2. *P. rhoeas*

In general, relative to the other flower species, *P. rhoeas* had a high number of insect visits but a shorter flowering period. For both years, the main visitors to *P. rhoeas* were bees, followed distantly by beetles. Almost no other insects visited, except for other insects in 2016. A scientific review of *P. rhoeas* is in agreement with our results, stating that solitary bees are indeed particularly frequent visitors of *P. rhoeas* [33].

The flowers of *P. rhoeas* have petals larger than any of the other studied species, the inside of the flower is very open, and the anthers are very easy to access. The flowers of *P. rhoeas* hold a large amount of pollen and very little or no nectar [34,35]. Thus, insect visits to *P. rhoeas* are motivated only by pollen collection. The narrow spectra of visitors to *P. rhoeas* (only bees, beetles, and other insects) is likely due to this fact. For insects seeking primarily pollen (e.g., wild bees [36]), *P. rhoeas* is an attractive choice.

In various countries, *P. rhoeas* has been presented as a problematic weed for crops. In Spain, it is reported as a principal weed of barley and wheat [37] and its seeds can lie dormant in the soil for over 80 years [38]. However, *P. rhoeas* is not considered an invasive weed—its seeds remain close to the mother plant, and the probability of them spreading from the edge of the field is low. Furthermore, the “Plantwise Knowledge Bank” [39] classifies *P. rhoeas* as only moderately competitive against wheat and reported that biomass and seed production were significantly reduced by increasing crop densities.

In summary, although it has a short flowering period, because of its high attractiveness to bees and low invasiveness, *P. rhoeas* has the potential to contribute positively to pollinator conservation in agroecosystems.

4.1.3. *M. sylvestris*

In comparison to the other flower species, *M. sylvestris* had a moderate flowering period and a low number of insect visits. The most frequent visitors to *M. sylvestris* were bees in both years. All other insect groups visited during at least one of the years, although very infrequently. Overall low attractiveness of *M. sylvestris* to flower-visiting insects was also observed in other studies [40–42]. *M. sylvestris* has large corollas (the second largest amongst the studied species), although the nectar is concealed [43].

Gorenflo et al. [44], in Germany, also found bees to be the main visitor of *M. sylvestris*, comprising 98% of all insect visits. However, Gorenflo et al. observed much higher visitation frequencies from honeybees than from bumblebees or Halictidae bees. In our study, we observed mostly Halictidae bees and very few honeybees (see Supplemental Material, Section 1.1.2). These findings suggest that honeybees are avid visitors to *M. sylvestris*, and thus the comparably low visits from bees in this experiment may be at least partially due to the sparsity of foraging honeybees at the study site.

Many authors refer to *M. sylvestris* as a weed due to its widespread and persistent root system, and it can be invasive in food crops [45]. However, Dutoit et al. [46] did not find it to be invasive in cereal crops.

In summary, *M. sylvestris* was only seen to be moderately attractive to most pollinators, and it could be a problematic weed in some environments. However, in the right context, *M. sylvestris* could be a positive addition to agricultural landscapes for pollinator conservation because it is perennial and exhibited a moderately long flowering period.

4.1.4. *C. arvensis*

In general, relative to the other flower species, *C. arvensis* had a relatively low number of insect visits but a very long flowering period. The main insects visiting *C. arvensis* were bees and beetles. These results were slightly less favourable than another study (albeit located in Canada), which considered *C. arvensis* to be intermediate in terms of pollinator visitation rates compared to other wild flower species [47]. One reason why this species may not be particularly attractive to pollinators is that the nectar in their flowers is concealed [43].

Waddington [48] observed Halictid bees foraging at dense arrays of *C. arvensis* flowers (ranging from approximately 40–225 flowers/m²) and found that bee numbers increased linearly with flower density. In our study, *C. arvensis* coverage was relatively dense (mean = 197 flowers/m² in 2015 and mean = 112 flowers/m² in 2016); nevertheless, bee visits (which were mostly from the family Halictidae) were low compared to the other flower species. The greater flower density in 2015 may partially explain why there were more bees in that year.

C. arvensis is often considered to be a serious weed. Although *C. arvensis* is a relatively poor competitor for light, it competes effectively for soil moisture because of its extensive root system [49]. Its underground network of roots is said to reduce crop yields and interfere with harvesting operations [50] and allows the plant to persist after disturbances [49]. Seeds can remain viable in the soil for up to two decades [51]. Furthermore, it has been known to climb and knock over crop plants [52].

In summary, *C. arvensis* had a long flowering period, but is difficult to control, and exhibited mostly low attractiveness to flower visitors. Based on this study, *C. arvensis* does not appear to provide great value for pollinators in agroecosystems.

4.1.5. *S. oleraceus*

Compared to the other flower species, *S. oleraceus* had a short flowering period and a low number of insect visits. The only visitors to *S. oleraceus* were bees and beetles, and in 2015, only bees visited. The biggest downfall of *S. oleraceus* was the fact that the flowers were only open for a short period each day. This short daily period of bloom, also noted by Lewin [53] and Percival [54], greatly reduced its efficiency in attracting flower-visiting insects.

S. oleraceus may be invasive and has the potential to compete with cultivated plant species [55]. According to the US Forest Service [56], it is considered to be invasive in several countries. Weber [57] claims that its large stature and high nutrient uptake could cause soil impoverishment in heavily infested sites. On the other hand, it is not known to significantly invade high-quality natural areas and does not regenerate from root fragments and can thus be managed by cutting or mowing [57].

In summary, because of its very limited periods of daily bloom, low flowering period, and low attractiveness for all pollinator groups, these results do not indicate that *S. oleraceus* would be of particular benefit to agroecosystems for the purpose of supporting pollinators.

4.2. Monocultures vs. Mixed Stands

There was a high frequency of visits from bees and beetles to mixed plots, and in 2016 only, true bugs as well. In general, floral mixtures have the advantage of longer overall flowering periods and more functional diversity than a species in a monoculture.

Most of the flower species (except *S. oleraceus* and *M. sylvestris*) received more visits when growing in monocultures than in mixed stands. In a similar experiment by Barbir et al. [17], the same phenomenon was witnessed, in which higher visits were recorded in monocultures compared to mixed plots. As hypothesized by Barbir et al., the lower visitation rate to mixed plots could be a result of the lower floral density of each individual species, causing the probability that insects will see specific flowers from a distance to be lower. It is also more complicated for insects to travel from one plant to another, and visual or scent cues could be intercepted. For example, it is known that growing different crops in the same field, compared to growing them in monocultures, reduces the incidence of pests [58].

In summary, based on these results, it could be recommended that wild flowers sown for the conservation of pollinators should be arranged in clumps, rather than highly intermingled.

4.3. Implications of Pan Trap Results

Bees are usually considered the most important group of pollinators. When considering bee visits in our study, the high proportion of bees from the family Halictidae (95% of bee specimens) must be taken into consideration, as well as the low proportions of honeybees (2%) and bumblebees (0%). Bees from the genus *Halictus* are sometimes limited by their short tongues, which prevent them from extracting resources from flowers with deep corollas [59]. This is congruent with observations from our study, in which bees preferred *P. rhoeas*, which has an open, bowl-shaped corolla and is known to be pollinated by short-tongued bees [43]. *D. carota*, which has exposed nectaries and open accessible inflorescences [28,29], was also frequently visited by the bees.

Beetles are important pollinators due to their sheer abundance [60]. However, they often feed on floral tissue and in some cases can cause damage to plants and be considered pests [61]. Of the beetles observed, several were from the family Dermestidae, genus *Orphilus* (52% in 2015 and 34% in 2016). These beetles are not categorized in the literature as pests. There were also a significant number of small beetles from the family Mordellidae (34% in 2015 and 22% in 2016). These adults feed on the pollen of many different plants, especially from the families Apiaceae (such as *D. carota*) and Asteraceae (such as *S. oleraceus*) [62]. In our study, many mordellids were found on *D. carota*, but not on *S. oleraceus*. No claims were found in the literature suggesting that beetles from the Mordellidae family could be agricultural pests. Long and slender beetles from the families Cerambycidae, Meloidae, or Cantharidae were also observed in relatively high numbers (12% combined in 2015 and 9% in 2016). All three of these families commonly visit flowers, although their short tongues limit them to feed mostly from flowers with freely exposed nectaries [63], which could explain their attraction to *D. carota* in this study. The larvae of Cantharidae species are predators of soft-bodied insects, feeding on caterpillars and locust eggs, and can potentially reduce the impact of certain pests on crops [59]. Overall, no beetles frequently observed in this study were of any great concern as pests.

Although usually not considered to be significant pollinators, true bugs are common flower visitors with potential ecological significance [64]. Some species are known to be predators of other pest species and can be used to control soft-bodied insects, for example, aphids and caterpillars [65]. On the other hand, because most true bugs feed on plants, some species can be serious pests to cultivated crops [66]. The majority of the true bugs

observed in this study belonged to the species *O. lavaterae* (65% in 2015 and 96% in 2016). *O. lavaterae* is widespread throughout Europe [67], feeds on plants, and is trophically associated with the plant family Malvaceae, including *M. sylvestris* [68], as was observed in this study. It is not considered to be a pest [67]. Several larger true bugs from the families Lygaeidae or Pyrrhocoridae were also observed, likely *Lygaeus equestris* or *Scantius aegyptius* (32% in 2015 and 4% in 2016). *L. equestris* is a seed predator that feeds on a number of plant species and could be a pest of commercial seed crops [69]. *S. aegyptius* is not considered a plant pest and, according to Bryant [70], does not appear to pose any serious threats to agriculture or the environment. (Refer to Supplemental Material, Section 1.1, for the methodology and results of the insect identification using pan traps.)

4.4. Implications for Management.

Wild plant diversity can be easily maintained in agroecosystems by setting aside field margins and protecting them from pesticides, fertilizers, and disturbances. One common concern for farmers is that margins left to regenerate naturally may encourage pernicious weeds, which can spread into the crop and be difficult to control [4]. Marshall [71] claims that the perception weeds in field margins will invade crops is misguided and that the number of important weed species that originate in margins is limited. Nevertheless, Marshall further noted that when winter annuals dominate the boundary flora, as is typical in Mediterranean conditions, margins may have a more significant influence on the presence of weed flora. In these circumstances, specialized margin management strategies should be applied, for example, by sowing non-invasive perennial species to help provide a barrier against the spread of weeds from the field edge into the crops [4].

4.4. Study Limitations and Suggestions for Future Research

It is possible that because this was a research trial and plants were concentrated in a common area, the results could vary from what may actually occur when plants exist in field margins or are distributed throughout the landscape of a farm. Because the same plant species sampled within a site and year can receive very different groups of visitors [34], the results from this work may not be observed in different contexts or different years.

During the literature review for this study, it was observed that the information available about specific wild plant species (i.e., traits, attractiveness to pollinators, and weediness) is limited and extremely out of date. New research is needed on the ecosystem services provided by individual wild plant species. It is recommended that more studies be conducted examining a wide range of wild plant species and their potential contributions to agroecosystems. Research is also required on the viability of different non-invasive wild plant species to be sown in specific regions and varying conditions.

It is clear that participation in sustainable agriculture requires changes in economic frameworks, including fair markets and prices, and governmental incentives [72]. For example, farmers could be compensated for losses in income which may arise as a result of adopting strategies for maintaining biodiversity [5]. The hope is that this work will help lead the way for the development of realistic management strategies sensitive to the realities of farmers for efficient and environmentally sustainable farming, shifting agricultural paradigms to create more robust agroecosystems.

5. Conclusions

- Overall, *D. carota* had the highest number of insect visits, followed by *P. rhoeas*. *C. arvensis*, *M. sylvestris*, and *S. oleraceus*, which had lower numbers of visits.
- *D. carota*, *P. rhoeas*, and *M. sylvestris* were found to be the most likely to support pollinators in agroecosystems. *C. arvensis* and *S. oleraceus* were found to be less likely to contribute to pollinator conservation.
- It is recommended that wild flowers sown for the conservation of pollinators be arranged in clumps, rather than highly intermingled, in order to improve visitation rates.
- Wild plants are important aspects of sustainable farms, helping to maintain biodiversity and ecosystem functioning, and should be promoted in order to dispel

common misconceptions and encourage their acceptance. Continued effort is needed to translate science to policy and engage with farmers to incorporate new strategies by providing them with financial and logistical support.

Supplementary Materials: The following are available online at <https://www.mdpi.com/article/10.3390/agronomy11071314/s1>, Insect identification with traps; Table S1. Effects of flower treatment, year, and their interaction on the length of the flowering period; Table S2. Effects of flower treatment, year, and their interaction on the average number of flowers in the plots.

Author Contributions: Conceptualization and methodology, J.M., J.I., and J.L.G.-A.; formal analysis, J.M. and E.H.P.; investigation, J.M. and J.I.; writing—original draft preparation, J.M. and E.H.P.; writing—review and editing, J.M., J.I., E.H.P., and J.L.G.-A.; supervision, J.I. and J.L.G.-A. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by FEDER (European Regional Development Funds) and the Spanish Ministry of Economy and Competitiveness (projects AGL2012-33736 and AGL2015-64130-R). The Natural Sciences and Engineering Research Council of Canada (NSERC) provided J.M. with a doctoral scholarship.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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