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Final Thesis

**Can flower strips increase beneficial  
arthropods in greenhouses?**

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## Abstract

Apparent insect population declines represent potential ecosystem service losses, especially in terms of pollination and pest control. Such losses go hand in hand with the growth of intensive agricultural systems, landscape simplification, and disappearing “semi-natural” habitats. Agri-environmental schemes aim to contrast negative trends and enhance agricultural production by favoring conditions whereby benefits are derived from increased biological diversity. Flower strips, enriched meadows, and remnant or designed semi-natural areas serve as examples of Green Infrastructure elements commonly prescribed to connect farmland with the surrounding landscape in favor of beneficial arthropods. Ideally, pollinator, predator, and parasitoid functional groups use these spaces as foraging, nesting, and overwintering sites and in turn bring pollination and pest control services to adjacent cultivated areas. While various studies have explored how the different arthropod functional groups respond to different interventions, it is less clear if Green Infrastructure elements export beneficial arthropods to specific agricultural structures, especially greenhouses. We set out to measure the abundance of beneficial arthropods belonging to pollinator, predator, and parasitoid functional groups on two organic farms in the Veneto region of Italy. Arthropods were captured within commercial greenhouses using pan traps along transects at varying distance from greenhouse exteriors. Greenhouse areas had either 1) a flower strip installed nearby or 2) no flower strip installed nearby. Relative abundance of pollinators and “pest control” arthropods (parasitoids and predators, together) was modeled in relation to distance from greenhouse exteriors. Results indicate increased beneficial arthropod abundance in greenhouse areas with nearby flower strips, along with a negative correlation between abundance and distance from greenhouse exterior. This trend was more significant for pollinators than for pest control arthropods, and it did not necessarily hold for greenhouse areas lacking flower strips. As such, the flower strips considered in this study appear to accomplish, to a degree, their intended purpose of increasing beneficial arthropods in greenhouses. Future studies on flower strip composition and configuration in the context of greenhouses should focus on clarifying recommendations and quantifying net benefits in terms of ecosystem services leading to increased adoption of Green Infrastructure measures among farm managers.

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## Introduction

In recent years, various studies have documented the decline of insect populations on multiple continents (Sánchez-Bayo and Wyckhuys 2019; Wagner 2020). Proposed drivers include simplification of the landscape, use of pesticides, and elimination of semi-natural habitats, as well as compound interactions among multiple factors (Goulson et al. 2015; Weisser et al. 2023). Such declines threaten biodiversity, plant-pollinator networks, and agricultural production (Dicks et al. 2016; IPBES 2017; Ramos-Jiliberto et al. 2020).

Reported insect declines cause particular concern because unmanaged insect populations provide multiple ecosystem services or “...benefits humans derive from ecosystems,” as described in the Millennium Ecosystem Assessment (2005). Pollination and pest-control, for example, commonly fall within the category of “regulating services” that generate benefits indirectly by regulating ecosystem processes (Balasubramanian 2019). Further, pollination and pest-control services are associated with specific arthropod functional groups, namely, pollinators, predators, and parasitoids (Klein et al. 2007; Kremen and Chaplin-Kramer 2007). Klatt et al. (2014) used strawberries as an example to demonstrate that bee-mediated pollination is key to fruit and berry production (see also Campbell et al. 2017) and, hence, both important for a healthy human diet and likely undervalued as a service. Similarly, Klein et al.’s (2007) review found that a significant portion of commercial crops produce more when visited by pollinators (or require animal pollination outright). Meanwhile, Holland et al. (2016) maintain that the natural predators of crop pests also protect and enhance production by reducing crop loss. Reduction or elimination of these services at best increases the cost of agricultural production—for example when crop pollination relies on imported honey bees (*Apis* spp.)—and at worst threatens our ability to provide food for a growing human population (Garibaldi et al. 2016).

As such, multiple initiatives and policies have sought to characterize the nature of pollination and pest control services, to understand the causes of insect population declines, and to define interventions designed to favor beneficial insects in agricultural settings. The Common Agricultural Policy (CAP) in the European Union and the Farm Bill in the United States serve as examples of policies promoting ecological intensification in agricultural settings (Albrecht et al. 2020), whereby elements of biological diversity or “nature-based” alternatives substitute

or complement external inputs to intensive farming systems (Kleijn et al. 2019). Also in this vein, the European Union’s proposed Farm to Fork strategy seeks to increase food production through the promotion of organic agriculture and practices that favor sustainability, resilience, and biodiversity in general (European Commission 2020). Ideally, such an approach sidesteps the negative consequences of conventional agricultural intensification (e.g., pollution, habitat loss) while increasing food production for human consumption (Garibaldi et al. 2019). It is worth noting that government-supported schemes likely rank agricultural production over the conservation of ecosystem services in order of importance and, as such, fall short of the spirit of the 2010 international Convention on Biological Diversity (Klatt et al. 2014).

The concept of Green Infrastructure (GI) provides one lens through which to view agriculture’s contribution toward “a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services” (European Commission 2013). Though urban and peri-urban landscapes tend to attract the bulk of Green Infrastructure research (Chatzimentor et al. 2020), Yacamán Ochoa et al. (2020) stress agriculture’s importance in furthering common GI goals—such as preserving open spaces, building resiliency in the face of global change, and strengthening connectivity between urban and semi-natural areas—and argue for specific guidelines relating to sustainable agriculture incorporating a multi-functional perspective. Schidt and Hauck (2018) also make the case for improved clarity and consistency in guidelines and recommendations and cite perceived ecosystem disservices and competing incentives as headwinds to more widespread acceptance of GI measures among farmers.

Various Green Infrastructure elements such as hedgerows (Kremen et al. 2019), uncultivated “semi-natural” areas (Morandin and Winston 2006), and species-rich meadows (Tonietto and Larkin 2018) are commonly proposed as nature-based solutions favoring pollinators, predators, and parasitoids in the landscape. Within this array of solutions, flower strip plantings stand out as an increasingly adopted intervention aimed at augmenting ecosystem services in intensive agricultural settings (Kowalska et al. 2022). Selected mixes of flowering resources, planted within fields or along margins, ideally support beneficial arthropods by providing food (Ouvrard et al. 2018), shelter (Tschumi et al. 2015), and nesting habitat (Blaauw and Isaacs 2014).

We have begun to develop a picture of how Green Infrastructure elements influence the abundance and richness of beneficial arthropods in agricultural settings—especially in open fields: Haaland et al.’s (2011) review found many studies demonstrated that insect abundance and diversity could be increased by sowing wildflower strips. Further, Palmeri’s (2020) meta-analysis highlighted the importance of flower strip composition: while plant species with open, short corollas and high nectar and pollen content were enough to increase pollinator abundance, a variety of plant species with different floral morphologies lead to higher insect species richness. What’s more, a growing body of evidence suggests that beneficial arthropod presence associated with flower strips translates to positive outcomes for commercial crops (Albrecht et al. 2020; Blaauw and Isaacs 2014; Campbell et al. 2017; Klatt et al. 2014).

Still, it is less clear how flower strips influence the abundance of pollinators, predators, and parasitoids spatially within specific agricultural structures, namely greenhouses (but see Li et al. 2021). Hence, we set out to investigate how the abundance of the primary beneficial arthropod functional groups varies with distance from two types of greenhouse exteriors: those with adjacent flower strips and those without adjacent flower strips. We tested the following hypotheses by trapping and counting arthropods along transects within greenhouses and modeling the abundance of pollinators, predators, and parasitoids in relation to distance:

- 1) Flower strips can increase the presence of beneficial arthropods within adjacent greenhouses, and a negative correlation exists between beneficial arthropod abundance and distance from flower strips.
- 2) The various functional groups considered (pollinators, predators, and parasitoids) respond differently to the effect of distance from flower strips; more mobile pollinators may move further toward greenhouse interiors than predators or parasitoids.
- 3) Beneficial arthropod abundance responds differently in greenhouse areas with and without adjacent flower strips.

A better understanding of how agricultural operations stand to benefit by implementing Green Infrastructure elements should help simplify recommendations, clarify messaging, and improve adoption—even in the most intensively exploited landscapes.



## Materials and methods

### Study area

Insect populations were sampled on two organic farms (as defined by Regulation 2018/848 of the European Parliament) in the Veneto Region of northern Italy during summer, 2023. The Veneto region is one of the most industrialized and populous regions of Italy with highly intensive and productive agriculture (Dal Ferro et al. 2016). The two study sites (Figure 1), Società Cooperativa Agricola Ca' Magre and Campo Calandro, are situated within the Po River Valley, the approximately 74,000 km<sup>2</sup> lowland, partially intersecting the Veneto Region, accounting for 40% of the nation's GDP, and home to 16 million people (Bozzola and Swanson 2014; Pijl et al. 2018). Here, the landscape has been highly modified with agriculture and industrial zones making up 70% and 20% of land use, respectively (Bonato et al. 2019).

Berti et al. (2014) describe the Po Valley as representative of a sub-humid climate receiving between 800 mm and 1000 mm rainfall, annually, with winters slightly drier than summers and yearly average temperatures ranging from 10° C to 14.4° C. According to Masin et al. (2010), January mean low temperature in the Veneto Region is -1.5° C while July mean high temperature is 27.2° C.

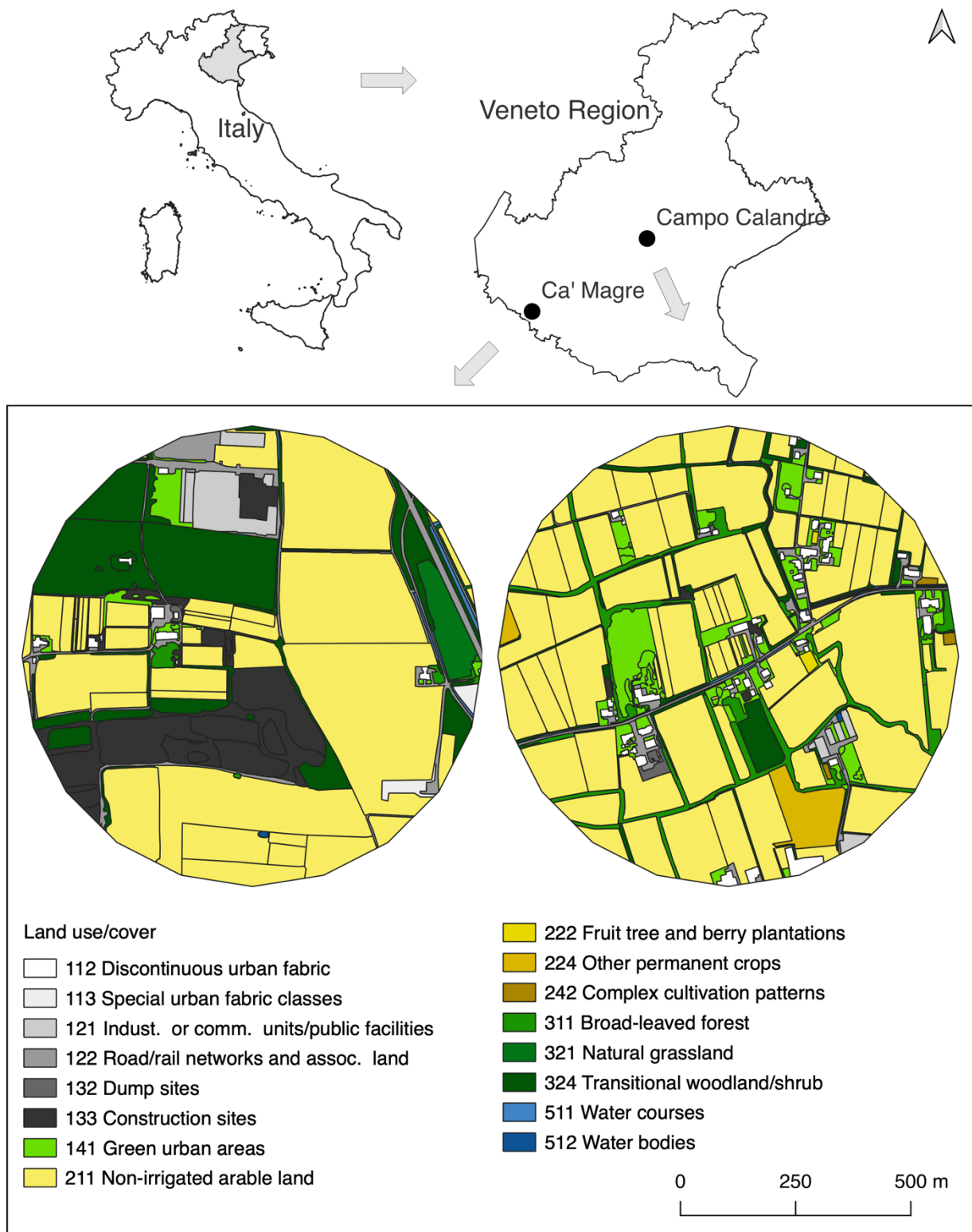


Figure 1. Ca' Magre and Campo Calandro study sites within the context of Italy's Veneto Region. European Environment Agency Corine Land Cover classifications are shown within a 500 m radius of each farm for descriptive purposes. Map created in QGIS (QGIS.org 2024).

## *Società Cooperativa Agricola Ca' Magre*

Società Cooperativa Agricola Ca' Magre is found in the southwestern part of the Veneto Region (~ 45.273670 N, 11.007157 E) and described by cartographic unit card BA1.1 (ARPAV 2018a) as an area of alluvial plains between 13 and 43 meters above sea level, with soils La Casetta (40%), Capitello (35%), and Le Maraiole (25%)—World Reference Base (WRB) groups Cutanic Luvisols (Hypereutric), Haplic Arenosols (Calcaric, Hypereutric), and Cutanic Luvisols (Hypereutric, Orthoarenic), respectively. Primary European Environment Agency Corine Land Cover (CLC) types (Kosztra et al. 2019) within a 500 m radius of the study site include non-irrigated, arable land (~ 54%), transitional woodland/shrub (~ 18%), construction sites (~ 13%), and road/rail networks and associated land (~ 6%).

The operation in the immediate vicinity of our sampling effort was composed of twenty-one “high tunnel” or “hoop house” style greenhouses, each measuring approximately 4.6 m wide by 40 m long. Ends of each greenhouse were left uncovered allowing for atmosphere and insect exchange with surroundings. Here, farm managers had chosen to seed a commercial flowering cover crop mix (hereafter “flower strip”) in seven of the eight westernmost greenhouses. Thus, sampled greenhouses were arranged parallel to the flower strip, and side walls of greenhouses 8-12 were rolled up to a height of approximately 1 m to allow free arthropod passage between flower strip and pan traps.

At the beginning of this study, Ca' Magre greenhouses were occupied with the following, in order from west to east: flower strip (n = 6), fallow (n = 1), flower strip (n = 1), fallow (n = 2), lettuce (n = 1), fallow (n = 1), tomato (n = 9). The nine structures occupied by tomato plants were separated from their surroundings by fine mesh screen in anticipation of *Bombus* sp. release. The lettuce crop did not exhibit flowering resources, hence greenhouse 11 was considered empty for the purpose of this study. Total flower strip area measured approximately 1,200 m<sup>2</sup> (4.6 m effective width x 40 m length x 7 greenhouses). Figure 2 shows Ca' Magre greenhouse layout and plantings.

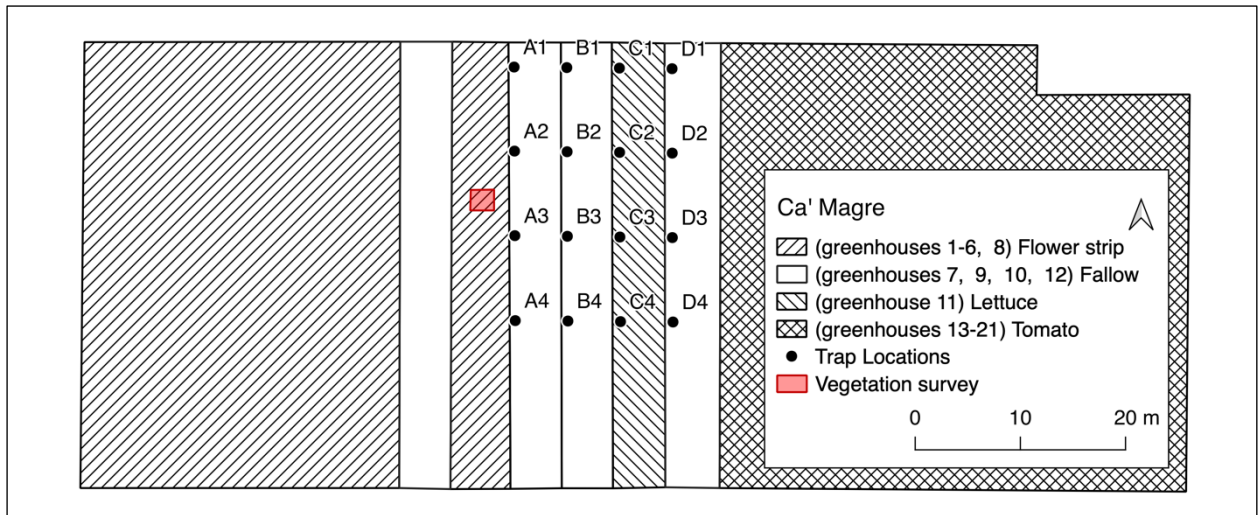


Figure 2. Pan trap placement and labels, vegetation survey plot, and greenhouse crops in the immediate vicinity of the Ca' Magre study site at the start of the 2023 growing season. Traps were deployed in 4 out of 21 total greenhouses (those devoid of flowering resources throughout the June-July arthropod sampling campaign). Sampled greenhouses (no. 9-12) were arranged parallel to the flower strip in greenhouse no. 8. Map created in QGIS (QGIS.org 2024).

### Campo Calandro

Campo Calandro, meanwhile, is located nearer the central portion of the Veneto Region (~ 45.588003 N, 11.806134 E). Soils cartographic unit card BA2.3 (ARPAV 2018b) describes the local morphology as transitional alluvial plain between 0 and 40 meters above sea level, with dominant soil type Mogliano—WRB group Endogleyic Calcisols (Orthosiltic). The area within a 500 m radius of the study site is dominated by European Environment Agency CLC types non-irrigated arable land (~ 70%), green urban areas (~ 8%), broad-leaved forest (~ 6%), transitional woodland/shrub (~ 5%), and road/rail networks and associated land (~ 3 %).

Our sampling effort took place in three greenhouses, similar in style to those described above. The westernmost structure (S3) measured 70 m in length by 9.9 m in width, the middle structure (S2) measured 50 m in length by 8.7 m in width, and the easternmost structure (S1) measured 50 m in length by 7.8 m in width. Open field separated greenhouses S2 and S3. At the start of this study, tomato, eggplant, pepper, and green beans were grown in greenhouse S3; tomato, eggplant, pepper, and lettuce were grown in greenhouse S2; and greenhouse S1 remained fallow. The open field separating S3 and S2 was occupied with zucchini, fennel, and lettuce. Figure 3 shows Campo Calandro greenhouse site plan and plantings.

At Campo Calandro, a native flowering plant mix (hereafter “flower strip”) had been seeded along the southern edge of the property as part of a previous habitat restoration project. This included 104 linear meters of 0.5-m-wide flower strip passing the southern end of all greenhouses, and a nearly 100 m<sup>2</sup> area located just to the south of greenhouse S1. For the purpose of modeling arthropod abundance, Campo Calandro greenhouses were divided into two treatment blocks: the “flower strip treatment block” (southern half of each greenhouse) had flower strips installed just outside, while the “no flower strip treatment block” (northern half of each greenhouse) had no adjacent flower strips present.

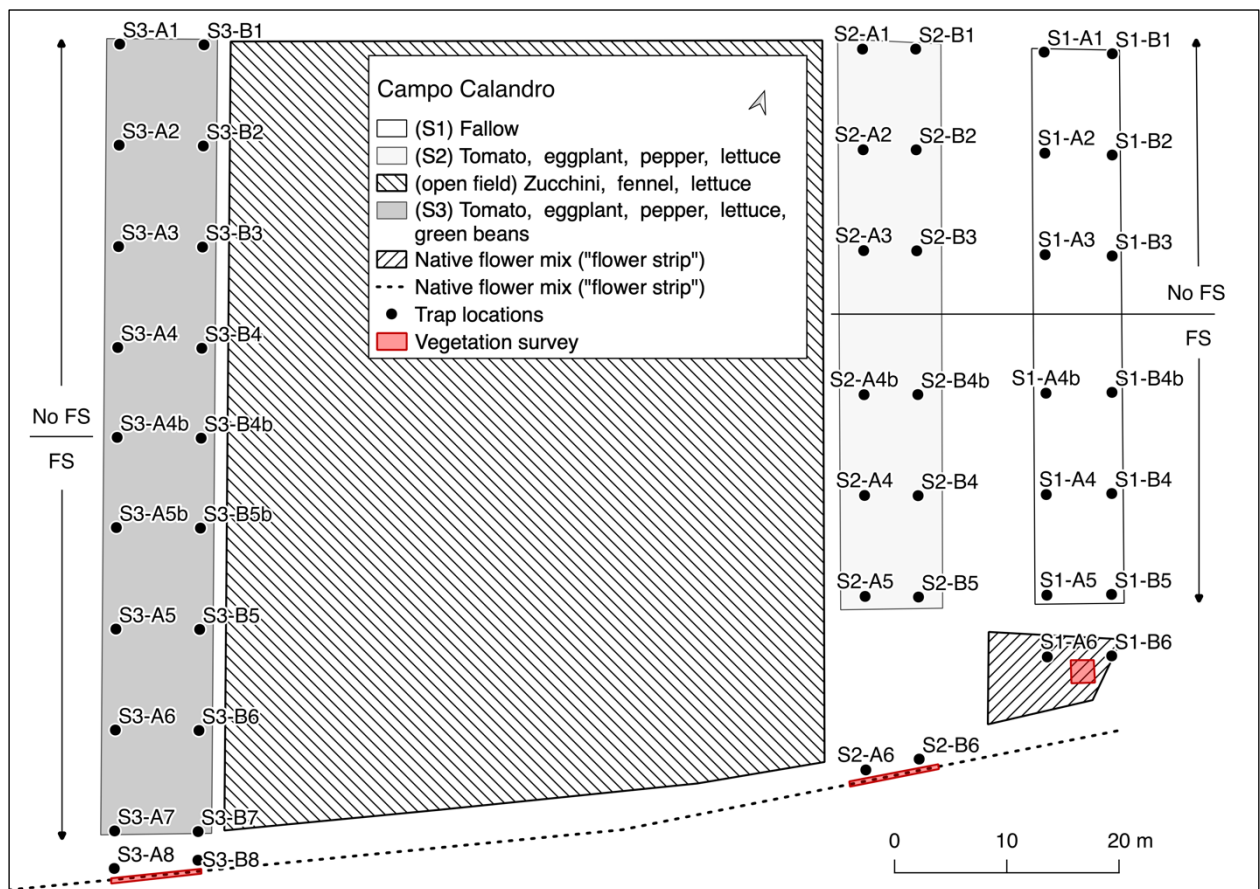


Figure 3. Pan trap placement and labels, greenhouses, crops, vegetation survey plots, and flower strips in the immediate vicinity of the Campo Calandro study site at the start of the 2023 growing season. Also shown are the flower strip and no flower strip treatment blocks used for the purpose of modeling arthropod abundance in relation to greenhouse entrances. Map created in QGIS (QGIS.org 2024).

### Flower strip vegetation

Flower strip plant species, relative abundance, average plant height, total percent cover, total percent forb cover, and total percent entomophilous species cover are summarized for both

farms in the appendices for purely descriptive purposes. Plant species were determined according to Bartolucci et al. (2018) and Galasso et al. (2018) for vascular plants native to Italy and vascular plants not native to Italy, respectively. Ca' Magre flower strip characterization comes from a June 30, 2023 survey of a 2 x 2 m representative quadrat of flower strip, coinciding with the start of the sole Ca' Magre arthropod sampling campaign (see Appendix A for plant species relative abundance table and Appendix B for survey summary statistics). Campo Calandro vegetation, meanwhile, was surveyed twice within two 0.5 x 8 m sections of flower strip in proximity to greenhouses S2 and S3, and twice within a 2 x 2 m quadrat of flower strip in proximity to greenhouse S1. Surveys occurred on July 11, 2023, and September 25, 2023—one vegetation survey corresponding to each Campo Calandro arthropod sampling campaign (see Appendix C for early season plant species relative abundance table, Appendix D for late season plant species relative abundance table, and Appendix E for summary statistics regarding both surveys).

#### Arthropod trapping

Arthropods were sampled at Ca' Magre and Campo Calandro during summer 2023, using “pan trap” style traps (Figure 4) consisting of blue, white, and yellow consumer-grade polystyrene plastic bowls (depth: 4.5 cm, top diameter: 17 cm, bottom diameter: 12.5 cm) filled with approximately 400 ml water and a drop of neutral detergent (Clear & Natural neutral liquid soap, MIL MIL 76 Spa, Landion, Italy) to decrease surface tension as described in Moreira et al. (2016) and Westerberg et al. (2021). The three colors were chosen, based on a review of the available literature (see Campbell and Hanula 2007; Vrdoljak and Samways 2012; Heneberg and Bogusch 2014; Acharya et al. 2021; Buffington et al. 2021; Jaques et al. 2023), as likely to collect the variety of insect orders assumed present in such a setting, including functional groups of interest such as hymenopteran pollinators and parasitoids. Blue and yellow bowls were achieved by painting white bowls with Luxens brand “fluorescent blue” and “fluorescent yellow” spray paint (ADEO Services, Ronchin, France). The bowls were fixed approximately 70 cm above the ground, in sets of three (one of each color), by means of a wooden stand driven into the ground.

The pan traps were left in place for forty-eight hours, after which the contents of each bowl were transferred to individual 50 ml graduated polypropylene test tubes (Ø 30 mm x 115 mm

with screw cap, Meus srl, Piove di Sacco, Italy) taking care to eliminate excess water without discarding arthropods. Test tubes were labeled with collection date, site name, trap position, and pan color to facilitate subsequent analyses. Samples were immediately placed on ice to retard degradation.

Later, contents were filtered from solution, using a conical paper filter and funnel in the laboratory, and transferred (along with sample label) to smaller, 15 ml graduated polypropylene test tubes ( $\varnothing$  17 x 120 mm with screw cap, Aptaca spa, Canelli, Italy) for preservation under 70% ethanol solution until time of identification. The transfer process occurred in most instances within twenty-four hours of sample collection and in all cases within forty-eight hours.



*Figure 4. Pan traps were constructed of blue, white, and yellow plastic bowls, containing 400 ml of water and a drop of neutral detergent, staked approximately 70 cm aboveground. Traps were left in place for 48 hours and contents were collected in polypropylene test tubes for subsequent identification (photo credit Simone Preo).*

### *Trap layout and collection schedule*

At the Ca' Magre study site, pan traps were deployed in 4 greenhouses (out of 21 total) not planted with flowering crops (greenhouses 9-12 in Figure 2). Though greenhouse 11 was planted with lettuce, it was not flowering during the June-July early arthropod trapping campaign. Individual trap positions were assigned alphanumeric labels A-D from west to east (corresponding to greenhouses 9-12) and 1-4 from north to south (corresponding to transects 1-4). A buffer of 1 m separated traps from the westernmost wall of each greenhouse. Moving in a north-south direction, trap placement began 2.5 m from each greenhouse entrance while the distance between traps measured 8 m. Trap series A, B, C, and D were separated by 5 m.

Traps were set and collected according to the schedule in Table 1 to test the effect of distance from flower strip on the abundance of pollinator, predator, and parasitoid arthropods. Trap series A, B, C, and D were deployed and sampled on different days to avoid confounding interactions between traps. Though two sampling campaigns were planned for Ca' Magre, only the early season (June-July) campaign was carried out due to the scheduled release of domestic *Bombus* sp. pollinators in greenhouses 13-21 concurrent with the planned late season (September) campaign.

Though one blue trap was found partially damaged in position D2 on July 5, 2023, it contained arthropods, and the data were retained—although they likely represent an acceptable underestimate—because white and yellow traps tend to catch more arthropods and more heavily influence results than do blue traps (see Figure 6 in results).

*Table 1. Pan trap deployment/sample collection schedule for Ca' Magre study site, June-July 2023.*

Date	Traps deployed	Contents collected
June 27	A1—A4	-
June 29	B1—B4	A1—A4
July 1	C1—C4	B1—B4
July 3	D1—D4	C1—C4
July 5	-	D1—D4

Pan traps were deployed in Campo Calandro greenhouses S1, S2, and S3 with A-series traps along the western wall of each greenhouse and B-series traps along the eastern wall of each greenhouse (Figure 3). A minimum buffer of 0.5 m was left between traps and greenhouse



walls and 5 m separated A-series traps and B-series traps. In general, starting from 2.5 m inside the north entrance of each greenhouse, traps were placed every 9 m, though an approximately 13 m gap was left between the centermost traps of greenhouses S1 and S2. In addition, a pair of pan traps was added adjacent to the flower strip outside the southernmost end of each greenhouse. Again, each trap was assigned an alphanumeric label representing greenhouse, A or B series, and number in increasing order from north to south.

Pan traps were deployed and collected according to the schedule in Table 2, to test the effect of distance from flower strips upon pollinator, predator, and parasitoid arthropod abundance. Here too, the given schedule sought to minimize confounding effects of interactions between traps. At Campo Calandro, two sampling campaigns were scheduled and both were carried out—the first in June-July and the second in September 2023.

On July 13, 2023, the blue, white, and yellow traps in position S2-A6 of Campo Calandro farm were found damaged. They were reset on July 17, 2023, and contents were collected on July 19, 2023. Similarly, the trap in position S1-A2 of Campo Calandro was missing a blue pan on September 16, 2023. As such, the data were rejected, the trap was reset with all three colored pans on September 18, and contents were collected on September 20, 2023.

Table 2. Pan trap deployment/sample collection schedule for Campo Calandro study site, June-July 2023 (early campaign) and September 2023 (late campaign). \*Traps S2-A6 and S3-B8 were found damaged on July 13, hence, they were reset on July 17 and contents were collected on July 19. Similarly, trap S1-A2 was missing a blue pan on September 16 so the corresponding data were rejected, and the trap was reset (all three colored pans) on September 18 with contents collected on September 20.

Date	Traps deployed	Contents collected
June 27	S1-A1, S1-B1, S1-A5, S1-B5, S2-A1, S2-B1, S2-A5, S2-B5, S3-A1, S3-B1, S3-A7, S3-B7	-
June 29	S1-A2, S1-B2, S1-A4, S1-B4, S2-A2, S2-B2, S2-A4, S2-B4, S3-A2, S3-B2, S3-A6, S3-B6	S1-A1, S1-B1, S1-A5, S1-B5, S2-A1, S2-B1, S2-A5, S2-B5, S3-A1, S3-B1, S3-A7, S3-B7
July 1	S1-A3, S1-B3, S1-A4b, S1-B4b, S2-A3, S2-B3, S2-A4b, S2-B4b, S3-A3, S3-B3, S3-A5, S3-B5	S1-A2, S1-B2, S1-A4, S1-B4, S2-A2, S2-B2, S2-A4, S2-B4, S3-A2, S3-B2, S3-A6, S3-B6
July 3	S3-A4, S3-B4, S3-A5b, S3-B5b	S1-A3, S1-B3, S1-A4b, S1-B4b, S2-A3, S2-B3, S2-A4b, S2-B4b, S3-A3, S3-B3, S3-A5, S3-B5
July 5	S3-A4b, S3-B4b	S3-A4, S3-B4, S3-A5b, S3-B5b
July 7	-	S3-A4b, S3-B4b
July 11	S1-A6, S1-B6, S2-A6, S2-B6, S3-A8, S3-B8	-
July 13	-	S1-A6, S1-B6, S2-A6*, S2-B6, S3-A8, S3-B8*
July 17	S2-A6*, S3-B8*	-
July 19	-	S2-A6*, S3-B8*
Sept. 12	S1-A1, S1-B1, S1-A5, S1-B5, S2-A1, S2-B1, S2-A5, S2-B5, S3-A1, S3-B1, S3-A7, S3-B7	-
Sept. 14	S1-A2, S1-B2, S1-A4, S1-B4, S2-A2, S2-B2, S2-A4, S2-B4, S3-A2, S3-B2, S3-A6, S3-B6	S1-A1, S1-B1, S1-A5, S1-B5, S2-A1, S2-B1, S2-A5, S2-B5, S3-A1, S3-B1, S3-A7, S3-B7
Sept. 16	S1-A3, S1-B3, S1-A4b, S1-B4b, S2-A3, S2-B3, S2-A4b, S2-B4b, S3-A3, S3-B3, S3-A5, S3-B5	S1-A2*, S1-B2, S1-A4, S1-B4, S2-A2, S2-B2, S2-A4, S2-B4, S3-A2, S3-B2, S3-A6, S3-B6
Sept. 18	S1-A2*, S3-A4, S3-B4, S3-A5b, S3-B5b	S1-A3, S1-B3, S1-A4b, S1-B4b, S2-A3, S2-B3, S2-A4b, S2-B4b, S3-A3, S3-B3, S3-A5, S3-B5
Sept. 20	S3-A4b, S3-B4b	S1-A2*, S3-A4, S3-B4, S3-A5b, S3-B5b
Sept. 22	-	S3-A4b, S3-B4b
Sept. 25	S1-A6, S1-B6, S2-A6, S2-B6, S3-A8, S3-B8	-
Sept. 27	-	S1-A6, S1-B6, S2-A6, S2-B6, S3-A8, S3-B8

## Arthropod determinations

Arthropods captured were identified in the laboratory, by direct observation under a stereo microscope, to the level of super-family where possible, though some taxa were identified to the family, genus (e.g. *Polistes* spp.), or paraphyletic group (e.g. “moths”) level. The identification process was carried out between December 2023 and April 2024. Each taxon was further assigned to a functional group (pollinator, predator, parasitoid) based on its role in an agricultural setting. Though some taxa could likely be assigned to multiple functional groups (or change functional groups through various life stages), for the purpose of our analyses each taxon was assigned to a single, dominant functional group, as described in Favarin et al. (2024).

The following taxa were counted and grouped in an “other” functional group, that was not considered in further analyses, as most constituent species were either understood to not carry out pollination or pest-control services (some are actually considered pests, themselves), or because they belonged to domesticated colonies introduced to anthropogenic ends: *Apis* spp., other coleopterans, other dipterans (such as Bibionidae, Cecidomyiidae, Chironomidae, Culicidae, Muscoidea, Simuliidae), Cynipoidea, Formicidae, other non-predatory heteropterans (generally Pentatomidae or “stink bugs”), other homopterans (generally Cicadoidea or “cicadas”), and Pompiloidea.

While the honey bees (*Apis* spp.) surely carry out pollination services in greenhouses, here they were not counted as pollinators because they were present solely due to the practice of bee husbandry. Also, Cynipoidea are commonly considered parasitoids, yet a non-trivial portion of the cynipoid wasps parasitize plants, inducing galls, hence their exclusion from the parasitoid functional group (Vårdal 2006). Similarly, the case could be made to include the Pompiloidea among the parasitoids (or even predators or flower visitors), with many species provisioning offspring with paralyzed prey, though an important family of “spider wasps,” the Pompilidae, prey exclusively on spiders (Waichert et al. 2015), other predators, limiting their potential net benefit to agricultural systems. Finally, although Aphidoidea, Collembola (springtails), Psocoptera, and Thysanoptera were observed, they were not counted as they did not belong to any functional group of interest and/or because our method of pan trapping may not have produced results representing the relative abundance of these groups.

## Modeling arthropod abundance

Arthropod abundance in blue, white, and yellow traps was summed to generate a composite value for each instance of each trap position, and individual taxa were combined by functional group. Parasitoids and predators were considered together in a “pest control” group to avoid singularity issues in analyses, likely stemming from numerous predator zero values, while pollinators were considered alone.

Generalized Linear Mixed Models (GLMMs) were generated to model pest control and pollinator arthropod abundance in relation to distance from flower strips. Where overdispersion was deemed an issue (R package AER, Kleiber and Zeileis 2008), a negative binomial distribution with log link (R package glmmTMB, Brooks et al. 2017) was preferred over the standard Poisson distribution with log link (R package lme4, Bates et al. 2015). The base R drop1 function (R Core Team 2024) was used to explore model improvement by dropping fixed terms.

In the case of Ca' Magre, where only one arthropod sampling campaign was completed (early season, June-July 2023), distance from flower strip was taken as the lone fixed factor and transect was included as the lone random factor (here, greenhouses were situated parallel to flower strips, hence, four transects of four traps each were taken to extend perpendicular to flower strips, spanning greenhouses 9-12—see Figure 2).

At Campo Calandro, greenhouses were positioned perpendicular to flower strips, and, for the purpose of these analyses, greenhouses were divided into two treatment blocks: those with flower strips adjacent to entrances and those without (Figure 3). Data deriving from pan traps located in the southern half of each greenhouse were included in the flower strip treatment block while data from pan traps located in the northern half of each greenhouse were included in the no flower strip treatment block. Pan traps positioned outside greenhouses, adjacent to the flower strips themselves, were excluded from analyses as were those located at the midpoint of greenhouse S3, as they straddled the two treatment blocks. Each treatment block was modeled separately, taking distance from nearest greenhouse entrance as the lone fixed factor and interaction between greenhouse and season as random factors. Thus, flower strip treatment block data were used to model arthropod abundance in relation to southern greenhouse

entrances and no flower strip treatment block data were used to model arthropod abundance in relation to northern greenhouse entrances.

## Results

### Arthropod determinations

During the summer 2023 arthropod monitoring campaign 8,997 individuals were captured in 336 pan traps on both farms. Orders represented were the Arachnida, Coleoptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera, and Neuroptera. Among recorded individuals, 1,028 were classified as pollinators, 164 were classified as predators, and 1,691 were classified as parasitoids. 6,114 arthropods did not belong to one of the above-mentioned functional groups of interest and they were labeled “other” and not considered in further analyses (Table 3). Figure 5 presents the composition of the major arthropod orders observed along with pollinator, predator, and parasitoid functional group assignments.

Solitary bees represented the majority of pollinators observed. Notably, *Apis* spp. were not counted among the pollinators as colonies of these domestic hymenopterans were introduced to the landscape to anthropic ends. The chalcidoid wasps of superfamily Chalcidoidea were the most numerous of the parasitoid hymenopterans. Among the dipterans, most (i.e. Bibionidae, Cecidomyiidae, Chironomidae, Culicidae, Muscoidea, Simuliidae) were not considered for further analyses, though Syrphidae and Tachinidae were classified as important pollinators and parasitoids, respectively. The hemipterans, mostly cicadas (Cicadoidea) and “stink bugs” (Pentatomidae), generally did not belong to functional groups of interest, though the Anthocoridae stood out as predatory Heteropterans. Many Coleopterans were considered uninteresting in terms of functional role in agriculture, though notable exceptions Cerambycidae and Cetoniidae were considered flower visitors and the Coccinellidae predators.

Yellow pan traps caught far more individual arthropods (4,616) than blue (1,928) or white (2,453) traps. Yellow traps also caught more pollinators, predators, and parasitoids than blue or white traps (Figure 6).

Table 3. Functional group assignments and references of the taxa identified following the 2023 arthropod sampling campaign.

Taxon	Order	Functional group	Reference
Astatidae	Hymenoptera	Parasitoid	Olszewski et al. 2021
Braconidae	Hymenoptera	Parasitoid	Gauld 1988
Ceraphronoidea	Hymenoptera	Parasitoid	Whitfield 1998
Chalcidoidea	Hymenoptera	Parasitoid	Whitfield 1998
Crabronidae	Hymenoptera	Parasitoid	Marchiori 2023
Diaprioidea	Hymenoptera	Parasitoid	Polaszek and Vilhemsen 2023
Ichneumonidae	Hymenoptera	Parasitoid	Gauld 1988
Mymarommatoidea	Hymenoptera	Parasitoid	Whitfield 1998
Platygastridae	Hymenoptera	Parasitoid	Whitfield 1998
Proctotrupoidea	Hymenoptera	Parasitoid	Polaszek and Vilhemsen 2023
<i>Sphex</i> spp.	Hymenoptera	Parasitoid	Evans 1966
Tachinidae	Diptera	Parasitoid	Stireman and Singer 2003
Apoidea	Hymenoptera	Pollinator	Lorenzo-Felipe et al. 2020
Cerambycidae	Coleoptera	Pollinator	Kariyanna et al. 2017
Cetoniidae ( <i>Oxythrea funesta</i> )	Coleoptera	Pollinator	Roquer-Beni et al. 2022
Chrysoidea	Hymenoptera	Pollinator	Gess and Gess 2006
Conopidae	Diptera	Pollinator	Stuke 2017
Eumenes	Hymenoptera	Pollinator	Fateryga 2020
“Moths”	Lepidoptera	Pollinator	Hahn and Brühl 2016
Rhopalocera	Lepidoptera	Pollinator	Frankie and Thorp 2009
Scoliidae	Hymenoptera	Pollinator	Nagasaki 2021
Symphyta	Hymenoptera	Pollinator	Barbir et al. 2019
Syrphidae	Diptera	Pollinator	Rader et al. 2016
Tenthredinidae	Hymenoptera	Pollinator	Liston 1980
Anthocoridae	Hemiptera	Predator	Saulich and Musolin 2009
Arachnida	Arachnida	Predator	Cotes et al. 2018
Asilidae	Diptera	Predator	Leppla et al. 2008
Coccinellidae	Coleoptera	Predator	Dixon 2000
Dolichopodidae	Diptera	Predator	Cicero et al. 2017
Hybotidae	Diptera	Predator	Stepanycheva et al. 2016
Chrysopoidea	Neuroptera	Predator	Oswald et al. 2002
<i>Polistes</i> spp.	Hymenoptera	Predator	Weseloh and Hare 2009

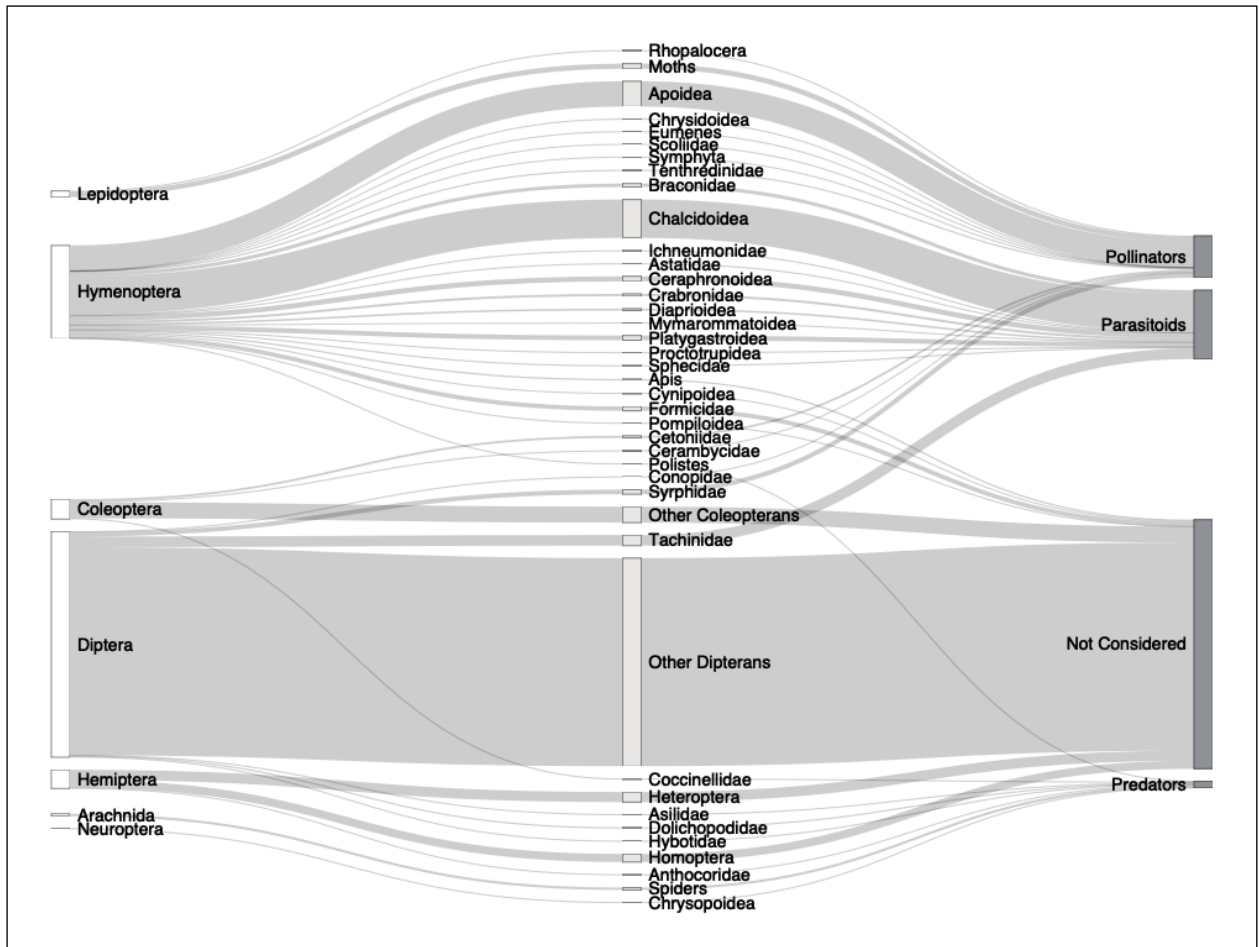


Figure 5. Taxa comprising the major arthropod orders captured during the summer 2023 monitoring campaign along with functional group assignments (R package networkD3 Sankey diagram, Allaire et al. 2017).



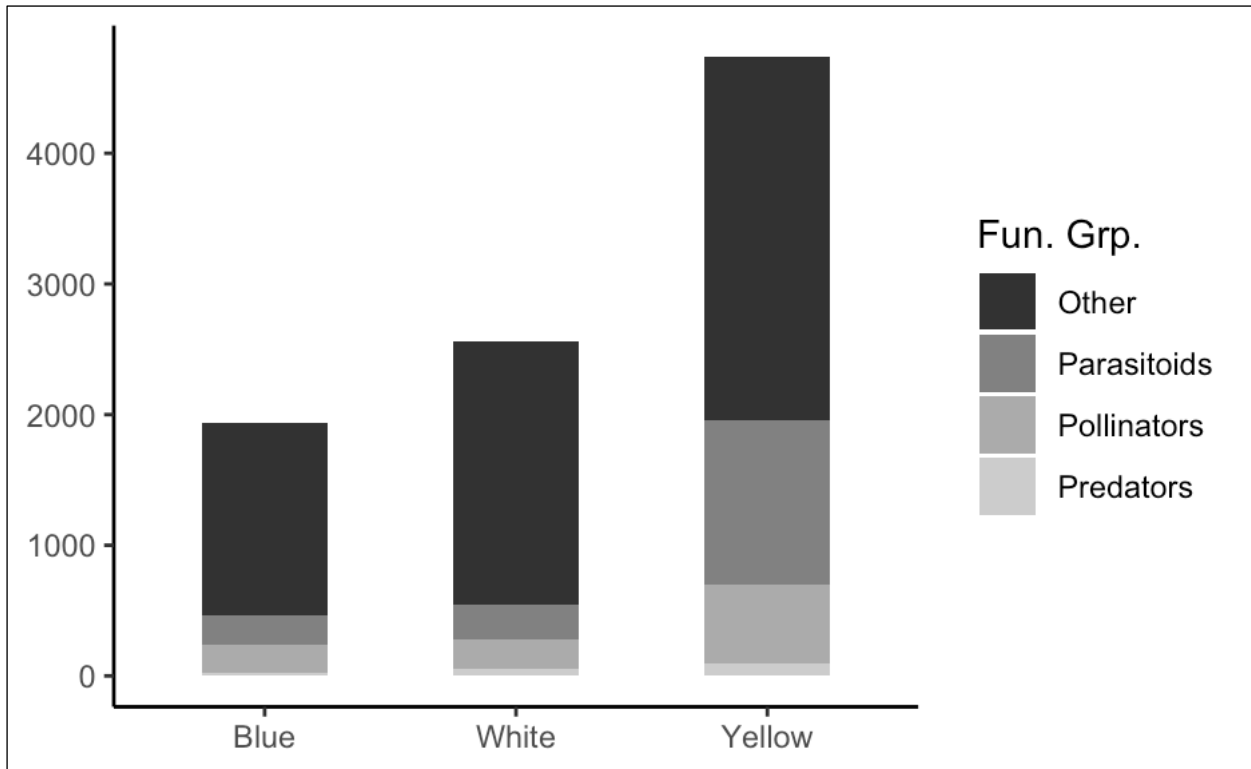


Figure 6. Arthropod functional group abundance by trap color, captured during the 2023 monitoring campaign. Yellow traps caught more arthropods than blue or white traps both in terms of functional groups and overall individuals (R package ggplot2, Wickham 2016).

### Modeled arthropod abundance

Summary statistics of the arthropod groups considered follow, in Table 4. Individual observations are the sum of blue, white, and yellow pan trap values. Arthropod counts are grouped by farm, treatment block, and ecosystem service the group is assumed to provide. The pest control group includes both parasitoids and predators, in part to manage for low predator numbers. Observations from pan traps S1-A6, S1-B6, S2-A6, S2-B6, S3-A8, and S3-B8 are excluded as the traps were positioned outside of greenhouses and did not belong to either of the two Campo Calandro treatment blocks (flower strip/no flower strip). Similarly, observations from pan traps S3-A4b and S3B4b are excluded as the traps straddled the two treatment blocks and did not belong, exclusively, to either block.

Table 4. Summary statistics regarding observed arthropods grouped by farm, treatment block, and assumed ecosystem service. FS = flower strip; No FS = no flower strip.

Farm	Block	Group	Min.	Max.	Mean $\pm$ SD	Individuals
Ca' Magre	-	Pest control	2	26	10.56 $\pm$ 6.45	169
Ca' Magre	-	Pollinator	3	26	10.50 $\pm$ 8.34	168
Campo Calandro	FS	Pest control	4	43	13.30 $\pm$ 8.42	532
Campo Calandro	FS	Pollinator	0	35	7.23 $\pm$ 6.23	289
Campo Calandro	No FS	Pest control	2	45	13.85 $\pm$ 10.03	554
Campo Calandro	No FS	Pollinator	0	36	7.75 $\pm$ 7.11	310

In general, the effect of distance was significant to models of pollinator abundance. This holds for the cases of Ca' Magre, where distance was measured from flower strips, the Campo Calandro flower strip treatment block, where distance was measured from south greenhouse entrances, and the Campo Calandro no flower strip treatment block, where distance was measured from north greenhouse entrances. The effect of distance was also significant to modeled pest control abundance at Ca' Magre Farm. Model statistics for the various combinations of farm, treatment block, arthropod group, and distance measured are collected in Table 5.

Table 5. Model statistics by farm, treatment block, arthropod group, and distance measured. FS = flower strip; No FS = no flower strip. Significance levels are as follows: 0 '\*\*\*'0.001 '\*\*'0.01 '\*'0.05 '.'0.1 '.'1.

Farm	Block	Group	Distance	Est. coeff.	SE	z-score	P	$\chi^2$	Sig.
Ca' Magre	-	Pest control	FS	-0.039	0.018	-2.187	0.028	4.844	*
Ca' Magre	-	Pollinator	FS	-0.126	0.016	-7.794	2.2e <sup>-16</sup>	70.854	***
Campo Calandro	FS	Pest control	S Entrance	-0.012	0.007	-1.671	0.094	2.802	.
Campo Calandro	FS	Pollinator	S Entrance	-0.044	0.012	-3.694	1.98e <sup>-4</sup>	13.848	***
Campo Calandro	No FS	Pest control	N Entrance	0.007	0.010	0.727	0.467	0.528	
Campo Calandro	No FS	Pollinator	N Entrance	-0.026	0.012	-2.148	0.031	4.633	*

### Ca' Magre arthropod abundance

Pest control arthropods significantly decreased with distance from flower strips on Ca' Magre Farm (Figure 7a). Abundance was modeled using a GLMM with negative binomial distribution and log link to account for likely overdispersion ( $\alpha = 2.195$ ). Slope effect was estimated at -0.039 and the difference in performance between models with and without the distance variable was significant ( $P = 0.028$ ). The Transect 1 random effect tended to push the intercept in the upward direction (Figure 7b) and its contribution to model performance was marginal

(full model AIC = 102.27, no random effect model AIC = 104.08, LRT full model vs. no random effect model = 0.051).

Similarly, pollinators significantly decreased along transects moving away from flower strips on Ca' Magre Farm (Figure 7c). Here, overdispersion was less concerning ( $\alpha = 0.464$ ) prompting a GLMM with Poisson distribution and log link. Slope effect was estimated at -0.126 and, again, the fixed term was significant in terms of model performance ( $P = 2.2e^{-16}$ ).

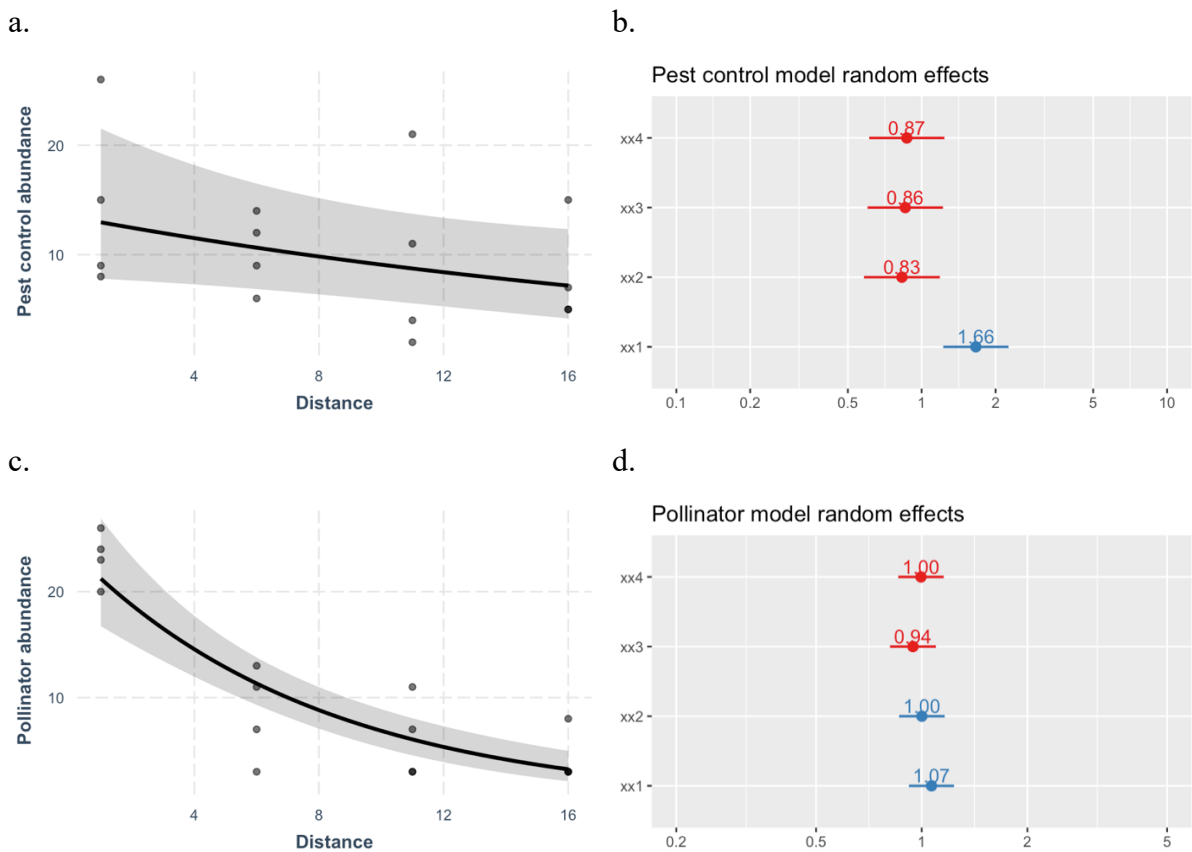
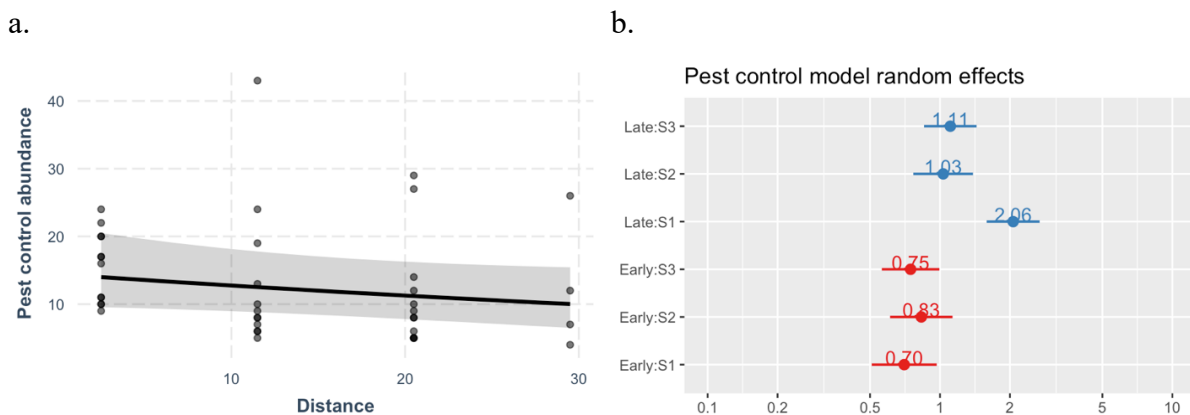


Figure 7. Ca' Magre modeled arthropod abundance for (a) pest control taxa (parasitoids and predators) and (c) pollinator taxa in relation to distance from flower strips. Plots include 95% confidence interval as well as original data points. Random effects plots related to the pest control abundance model and pollinator abundance model appear in (b) and (d), respectively. In the pest control case, the Transect 1 effect tended to raise the intercept (R package sjPlot, Lüdecke 2024).

## Campo Calandro arthropod abundance

Where flower strips had been installed adjacent to greenhouse entrances on Campo Calandro Farm, pest control arthropods decreased with distance from greenhouse entrance (Figure 8a), although not significantly. Abundance was modeled using a GLMM with negative binomial distribution and log link to account for likely overdispersion ( $\alpha = 4.193$ ). Slope effect was estimated at  $-0.012$ , though the difference in performance between models with and without the distance variable was not significant ( $P = 0.094$ ). The late season random effect tended to push the intercept in the upward direction for all greenhouses (Figure 8b) and model performance improved markedly with the inclusion of the random effect (full model AIC = 257.74, no random effect model AIC = 272.43, LRT full model vs. no random effect model =  $4.402e^{-05}$ ).

Here, pollinators significantly decreased moving away from greenhouse entrances with adjacent installed flower strips (Figure 8c). Again, overdispersion was concerning ( $\alpha = 2.627$ ) prompting a GLMM with negative binomial distribution and log link. Slope effect was estimated at  $-0.044$  and dropping the fixed term significantly worsened model performance ( $P = 1.982e^{-4}$ ). Early season random effects tended to influence model intercept in the upward direction for greenhouses S2 and S3 (Figure 8d), though the random effects likely were not important to model performance and AIC even slightly favored the model without random effects included (full model AIC = 228.50, no random effect model AIC = 226.85, LRT full model vs. no random effect model = 0.557).



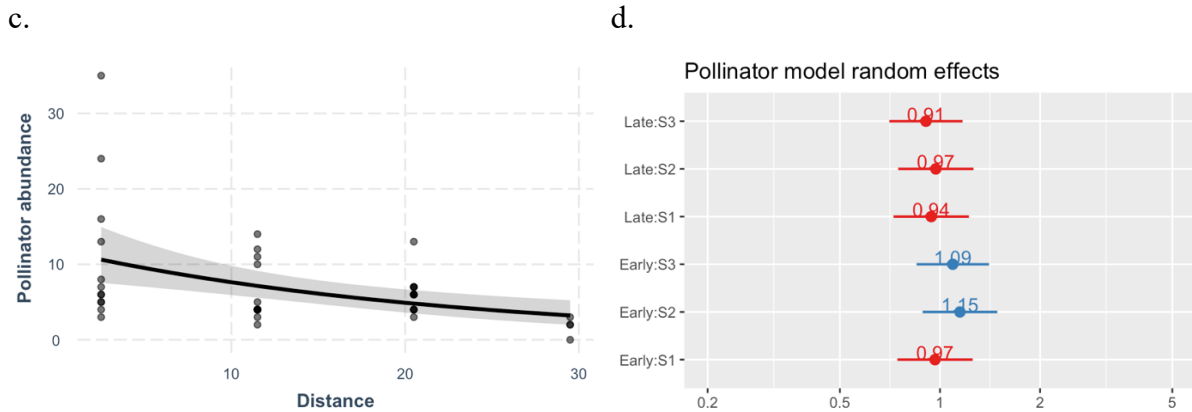


Figure 8. Campo Calandro flower strip treatment block modeled arthropod abundance for (a) pest control taxa (parasitoids and predators) and (c) pollinator taxa in relation to distance from greenhouse entrance nearest installed flower strips. Plots include 95% confidence interval as well as original data points. Random effects plots related to the pest control abundance model and pollinator abundance model appear in (b) and (d), respectively. In the pest control case, the late season effect tended to raise the intercept for all greenhouses. In the pollinator case, the early season effect tended to raise the intercept for greenhouses S2 and S3 (R package sjPlot, Lüdecke 2024).

For the Campo Calandro no flower strip treatment block, with no flower strips adjacent to greenhouse entrances, a positive, although not significant, trend emerged between pest control arthropod abundance and distance from greenhouse entrance (Figure 9a). Abundance was modeled using a GLMM with negative binomial distribution and log link to account for likely overdispersion ( $\alpha = 5.944$ ). Slope effect was estimated at 0.007 though distance was not significant in terms of model performance ( $P = 0.467$ ). The late season random effect again tended to push the intercept in the upward direction for all greenhouses (Figure 9b) and its inclusion appeared important to model performance (full model AIC = 275.79, no random effect model AIC = 284.23, LRT full model vs. no random effect model =  $1.232e^{-03}$ ).

Pollinators, on the other hand, showed a slightly significant decreasing trend moving away from greenhouse entrances in the no flower strip treatment block (Figure 9c). Once again, to compensate for overdispersion ( $\alpha = 4.254$ ) a GLMM with negative binomial distribution and log link was used. Slope effect was estimated at -0.027 and dropping the fixed term worsened model performance ( $P = 0.031$ ). Early season random effects tended to influence model intercept in the upward direction with regards to greenhouses S2 and S3 (Figure 9d) and in this case the random effect was likely important to model performance (full model AIC = 241.31, no random effect model AIC = 246.48, LRT full model vs. no random effect model =  $7.411e^{-03}$ ).

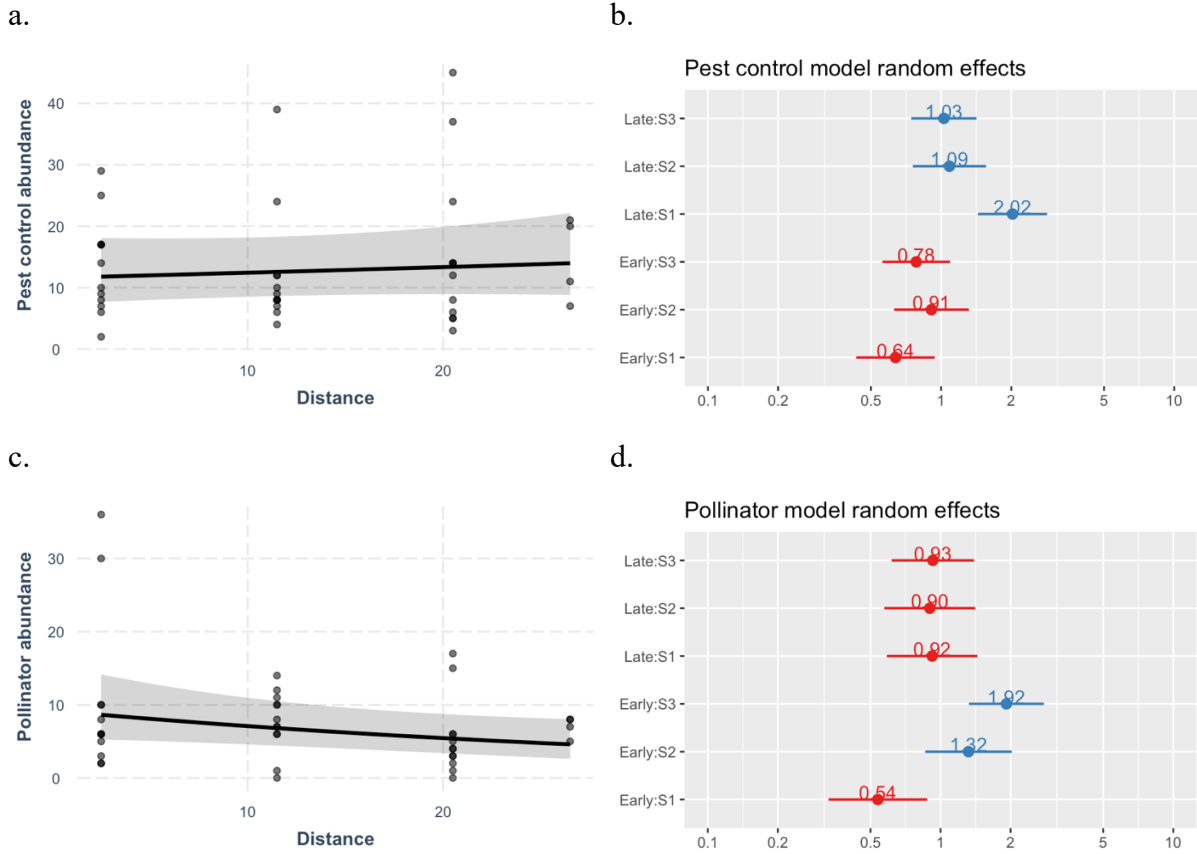


Figure 9. Campo Calandro no flower strip treatment block modeled arthropod abundance for (a) pest control taxa (parasitoids and predators) and (c) pollinator taxa in relation to distance from greenhouse entrance lacking installed flower strips. Plots include 95% confidence interval as well as original data points. Random effects plots related to the pest control abundance model and pollinator abundance model appear in (b) and (d), respectively. In the pest control case, the late season effect tended to raise the intercept for all greenhouses. In the pollinator case, the early season effect tended to raise the intercept for greenhouses S2 and S3 (R package sjPlot, Lüdtke 2024).

## Discussion

As expected, blue, white, and yellow traps caught a range of arthropods throughout the 2023 sampling campaign. This outcome was consistent with the findings of Campbell and Hanula (2007), Vrdoljak and Samways (2012), Heneberg and Bogusch (2014), Acharya et al. (2021), Buffington et al. (2021) and Jaques et al. (2023), and blue, white, and yellow traps deployed together likely detected the range of taxa present at each trap location during trap deployment. Further, many taxa important to agriculture—especially hymenopteran pollinators and parasitoids—were represented.

Most of the arthropods detected ( $n = 6,114$ ) did not belong to one of the three functional groups of interest (pollinators, predators, parasitoids), according to our classification scheme, and it is possible some of these “other” arthropods were, in fact, pests themselves. Many species of the dipteran Cecidomyiidae, for example, form galls on plants including commercial crops (Skuhrava and Skuhravy 1994). Among our three targeted functional groups, parasitoids ( $n = 1,691$ ) outnumbered pollinators ( $n = 1,028$ ), and predators ( $n = 164$ ) were the least represented. In fact, the low number of predators made it difficult to model this functional group alone in relation to distance from flower strips (model creation prompted singularity warnings). Hence the decision to group parasitoids and predators in an umbrella pest control group according to ecosystem service provided by these taxa in the context of organic farms of the Veneto Region of Italy.

One possible explanation for the low number of predators is the disturbance regime on the farms studied and/or the time since flower strip establishment: Hussain et al. (2021) claim predator population establishment lags behind that of other functional groups and Thorbek and Bilde (2004) cite instances of reduced predator abundance following mechanical operations on farms. Though the present study did not evaluate time since flower strip establishment, it is worthwhile noting that Ca' Magre flowering cover crop was just planted for the 2023 growing season and, at various times during the season, sections of Campo Calandro flower strip were disturbed by mowing activity and/or nearby road work.

Modeled Ca' Magre and Campo Calandro flower strip treatment block pollinator abundance appeared to support our first hypothesis of higher beneficial arthropod abundance in proximity

to flower strips and a negative correlation between abundance and distance. Higher pollinator abundance occurred in traps nearer flower strips on Ca' Magre Farm, and nearer greenhouse entrances with adjacent flower strips on Campo Calandro farm. Traps tended to capture fewer pollinators as distance increased along transects on both farms. The effect was most marked at Ca' Magre, where arthropods essentially enjoyed free passage from flower strips across greenhouses, as evidenced by the magnitude of the estimated slope effect as well as the significance of the fixed term to model performance.

A similar trend emerged among pollinators in the Campo Calandro no flower strip treatment block: higher abundance was observed near north greenhouse entrances, fell along transects moving toward greenhouse interiors, and the effect of distance was significant to model performance. Still, the magnitude of the estimated slope effect was less than that of both the Ca' Magre pollinator model, and the Campo Calandro flower strip treatment block model. It is possible the quantity of pollinators captured near the north greenhouse entrances of the no flower strip treatment block meant pollinators were arriving from sources besides the flower strips considered in this study. This may make sense if we consider various pollinators, including some bees and hoverflies, travel long distances while foraging, compared to other functional groups (Osborne et al. 2008; Doyle et al. 2020).

Modeled pest control arthropod abundance, meanwhile, only partially supported our first hypothesis. Pest control arthropods were observed in greater numbers nearer flower strips and, while a negative relationship existed between pest control arthropod abundance and distance, on Ca' Magre Farm and within the Campo Calandro flower strip treatment block, distance proved significant to Ca' Magre model performance, only. Such a negative trend did not hold for the no flower strip treatment block, and in fact flipped to a positive trend, though, as in the flower strip treatment block, the effect of distance was not significant in terms of pest control model performance.

Despite the low magnitude of the estimated slope effect of modeled pest control arthropod abundance associated with the Ca' Magre and Campo flower strip treatment block models, they would predict higher pest control arthropod abundance than pollinator abundance for much of the greenhouse transects. As such, our models appear to support only part of our second hypothesis: different arthropod functional groups respond differently to the effect of distance



along transects in terms of abundance. However, we would have expected more pollinators to travel further into greenhouse interiors. If this were the case, we would expect a reduced estimated slope effect in the pollinator abundance models along with greater estimated pollinator abundance near greenhouse interiors.

Regarding our third hypothesis, beneficial arthropods did respond differently in greenhouses with and without installed flower strips. This was evidenced, on Campo Calandro Farm, by higher pest control arthropod abundance near flower strip treatment block greenhouse entrances (modeled intercept 14.43 individuals) compared to no flower strip treatment block greenhouse entrances (modeled intercept 11.58 individuals). Additionally, pest control arthropod abundance followed a negative trend moving along transects within the flower strip treatment block and a positive trend moving along transects within the no flower strip treatment block (though the effect of distance was not significant to abundance models in either treatment block). Likewise, models predicted higher pollinator abundance near flower strip treatment block greenhouse entrances (modeled intercept 11.86 individuals) compared to no flower strip treatment block greenhouse entrances (modeled intercept 9.22 individuals). The effect of distance from greenhouse entrances on pollinator abundance, however, was fairly similar among the two treatment blocks: where flower strips were present outside greenhouses, our model estimated a 4% decline in pollinator abundance for every meter increase in distance; where flower strips were not present outside greenhouses, our model estimated 3% fewer pollinators for every meter increase in distance.

Though we did not explicitly set out to investigate the effect of season on arthropod abundance, this random factor appeared important to some of our models. Specifically, late season Campo Calandro arthropod sampling tended to return higher pest control abundance than early season sampling. This held for all three greenhouses and both treatment blocks, as evidenced by model random factor interaction between late season and greenhouses S1, S2, and S3. Further, this phenomenon appeared to be driven, at least in part, by the emergence of chalcid wasps of superfamily Chalcidoidea. These parasitoids showed up in numbers, with tens of individuals commonly found in yellow traps throughout late season Campo Calandro arthropod sampling. In all, 816 chalcid wasp individuals were identified in late season Campo Calandro pan traps, accounting for 69% of all late season parasitoids or 66% of all late season pest control arthropods. Perhaps parasitoid-host dynamics influenced the timing of parasitoid

hymenopteran emergence over the growing season, as in Quacchia et al. (2013) or Lauzière et al. (1999). This remains a potential line of future inquiry as our study did not focus on trends among known host species, or consider functional groups such as herbivores, precluding multicollinearity analyses among parasitoids and other functional groups. Also, no late season Ca' Magre data were available for comparison and the temporal distribution of parasitoid and predator abundance in greenhouses beyond Campo Calandro merits further investigation. Still, our models would predict higher pest control arthropod abundance within Campo Calandro greenhouses later in the summer.

The interaction between season and greenhouse was less consistent in modeled Campo Calandro pollinator abundance. Our models appear to predict higher early season intercepts for greenhouses S2 and S3. This holds for both the flower strip treatment block and the no flower strip treatment block, though the random effect was more important to model performance in the case of the no flower strip treatment block. This trend could possibly be related to the crops planted within the greenhouses themselves. At the start of the 2023 growing season, tomato, eggplant, pepper, and lettuce were planted in Campo Calandro greenhouses S2 and S3 (as well as green beans in S3, only), while greenhouse S1 remained fallow. The flowering vegetable crops themselves may have attracted pollinating arthropods inside greenhouses S2 and S3. Another possible explanation for increased pollinator abundance within greenhouses S2 and S3 involves the nature of the surrounding agricultural structures. While greenhouse S2 and S3 surroundings included cultivated open fields, a grassy parking area, and a drainage ditch, greenhouse S1 was bordered on three sides by a dirt road, a farm warehouse, and greenhouse S2. If we accept that pollinators tend to travel greater distances than other functional groups when foraging, the specific context within which greenhouses are embedded is likely important in terms of pollinator source populations. In either case, superfamily Apoidea was a primary driver of elevated early season pollinator abundance in Campo Calandro greenhouses S2 and S3, with 337 individuals retrieved from all traps. This amounts to 76% of the 444 pollinators recorded in the same greenhouses over the same period.

Finally, the random effect of transect appeared marginally important to our model of pest control abundance on Ca' Magre Farm. Transect 1 tended to drive our model intercept in the upward direction with higher numbers of pest control arthropods. We should recall that Ca' Magre transects ran perpendicular to greenhouse orientation and Transect 1 pan traps were

those nearest the north ends of greenhouses 9-12. It is possible that parasitoids and predators used the area outside greenhouses as a preferential pathway to move between the planted flower strip and Transect 1 pan traps. On the other hand, it is equally plausible that parasitoids and predators originated from some source besides the planted flower strip to arrive at the first set of pan traps encountered upon entering greenhouses. At the same time, it's worth noting that Ca' Magre transects spanned merely 15 m and were defined by just four trap positions. Thus, Transect 1 values were heavily influenced by three pan traps: on June 29, 2024 the yellow pan at position 1A caught 17 pest control arthropods including taxa Arachnida, Coccinellidae, Dolichopodidae, Braconidae, Chalcidoidea, Ichneumonidae, Tachinidae, Ceraphronoidea, Crabronidae, and Diaprioidea; on July 3, 2023 the yellow pan at position 1C caught 16 pest control arthropods including taxa Anthocoridae, Coccinellidae, Dolichopodidae, Braconidae, Chalcidoidea, Tachinidae, and Crabronidae; and on July 5, 2024 the yellow pan at position 1D caught 10 pest control arthropods including taxa Anthocoridae, Arachnida, Ceraphronoidea, and Crabronidae.

Observed trends on the two farms studied suggest that flower strips composed of both sown commercial cover crop mix and native flowering plant mix can export providers of ecosystem services to greenhouses—especially in the case of crop pollinators. Unfortunately, direct comparison of the efficacy of the different types of flower strip employed on the two farms was not possible because: 1) Ca' Magre flower strips were arranged parallel to greenhouses and greenhouse walls did not reach the ground, while Campo Calandro flower strips were positioned perpendicular to greenhouses and greenhouse walls extended nearer to the ground. As such, arthropods could move from flower strips across greenhouses at Ca' Magre while, at Campo Calandro, arthropods were constrained to movement along the length of greenhouses with limited between-greenhouse movement. 2) Ca' Magre greenhouses did not allow space for a no flower strip treatment block. 3) The planned late season Ca' Magre arthropod sampling campaign was not carried out due to the release of domesticated pollinators, severely limiting the available Ca' Magre data compared to the Campo Calandro data.

One difficulty with the present type of study lies in decisions regarding arthropod functional group assignments: various taxa encountered could have been assigned to multiple functional groups, yet our study design prescribed assignment to just one functional group based on understood importance in an agricultural setting of Italy's Veneto Region. If we take the scoliid

wasps of family Scoliidae as an example, we could have chosen to focus on the parasitic strategy of many species, though the decision was made to include individuals of family Scoliidae among the pollinators as “flower visitors.” What’s more, various taxa may change functional group as they mature through sequential life stages, such as some hoverflies of family Syrphidae: while larvae can act as aphid predators, adults visit flowers to collect nectar and pollen (Golding et al. 1999; Leroy et al. 2010). Finally, many of the arthropods encountered were not included in any of the three functional groups of interest. By not considering herbivores, for example, we may have missed important trends that could provide insight into the spatial and temporal distribution of other functional groups. Likewise, modeled arthropod abundance results might have changed had we chosen to classify certain taxa differently, allowed assignment to more than one functional group, or extracted further subsets of specific taxa. At a minimum, we might have achieved workable predator numbers under a different classification scheme. As Kremen et al. (2011) concluded in their evaluation of citizen science pollinator community surveys, “Further refinements of our classification system...” could improve the accuracy of our arthropod determinations.

## Conclusions

We set out to test whether flower strips can increase beneficial arthropods in greenhouses on organic farms in the Veneto Region of Italy. Flower strips are among increasingly prescribed Green Infrastructure elements designed to promote ecological intensification while linking to a network of natural and semi-natural areas to deliver multiple ecosystem services. Still, few studies have addressed the effect of flower strips on greenhouses and improved understanding and clarity should lead to increased acceptance of Green Infrastructure measures among farmers.

In our study, installed flower strips appeared to support the desired outcome of boosting beneficial arthropods in organic farm greenhouses. We have demonstrated a trend of higher pollinator abundance in portions of greenhouses with adjacent flower strips, and decreasing abundance along transects moving away from flower strips. Among pest control arthropods this trend was less pronounced, and the effect of distance on pest control abundance was significant in terms of model performance on only one out of the two farms where arthropod monitoring took place.

We also found that arthropod functional groups responded differently in terms of abundance versus distance from installed flower strips, though not in the way we had expected: pollinator abundance fell more rapidly than pest control abundance moving along transects away from flower strips and toward greenhouse interiors, in contrast to part of our second hypothesis. We expected pollinators to exhibit higher mobility and move further toward greenhouse interiors than pest control arthropods. If this were the case, we would expect pollinator abundance to fall less rapidly along transects and we should observe pollinators with greater frequency in central greenhouse area pan traps.

What's more, pollinator abundance decreased along transects, moving from greenhouse entrance to interior, even in the case where flower strips had *not* been installed. The opposite trend held for pest control arthropods where flower strips were lacking. This could mean pollinators used their higher mobility to arrive at greenhouses from sources other than the defined flower strips.

While both commercial flowering cover crop and native flowering mix appeared to positively influence beneficial arthropod abundance within organic farm greenhouses, our study design and the limitations of carrying out such a study on working farms prohibited direct comparison of the efficacy of each type of flower strip. We can offer, anecdotally, that 0.5-m-wide flower strips pose some practical limitations as any nearby mechanical activities, such as mowing or road work, can incidentally disturb this narrow configuration.

Further work is needed to develop clearer recommendations regarding flower strip composition and configuration—especially in the context of commercial greenhouses. Improved clarity and consistent messaging would likely promote increased adoption of such measures. Also, further studies should quantify ecosystem services derived from specific interventions, similar to the approach of Blaauw and Isaacs (2014). Greater understanding of potential net benefits linked to specific actions would help farm managers make decisions regarding adoption of Green Infrastructure elements. This is especially important considering the need to intensify agricultural output to feed a growing human population.

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## Appendices

Appendix A. Ca' Magre flower strip plant species relative abundance. A 2 x 2 m representative quadrat of flower strip was surveyed on June 30, 2023. Plant species were determined according to Bartolucci et al. (2018) and Galasso et al. (2018) for vascular plants native to Italy and vascular plants not native to Italy, respectively.

Species	Entomophilous? (Y/N)	Cover (%)
<i>Amaranthus retroflexus</i>	N	5
<i>Artemisia verlotiorum</i>	N	0.3
<i>Capsella bursa-pastoris</i>	Y	0.2
<i>Chenopodium album</i>	Y	2
<i>Crotolaria juncea</i>	Y	1
<i>Cynodon dactylon</i>	N	2
<i>Cyperus papyrus</i>	Y	5
<i>Fagopyrum esculentum</i>	Y	15
<i>Lamium amplexicaule</i>	Y	4
<i>Portulaca oleracea</i>	Y	3
<i>Sinapis alba</i>	Y	70
<i>Sorghum halepense</i>	N	10

*Appendix B. Statistics regarding Ca' Magre vegetation survey, June 30, 2023.*

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Dimensions (m)	2 x 2
Species present	12
Average plant height (cm)	100
Total cover (%)	100
Total forb cover (%)	85.3
Total entomophilous species cover (%)	32.3

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Appendix C. Campo Calandro early season flower strip plant species relative abundance. On July 11, 2023, two 0.5 x 8 m sections of flower strip were surveyed in proximity to greenhouses S2 and S3 while a single 2 x 2 m quadrat of flower strip was surveyed in proximity to greenhouse S1. Plant species were determined according to Bartolucci et al. (2018) and Galasso et al. (2018) for vascular plants native to Italy and vascular plants not native to Italy, respectively.

Species	Entomophilous? (Y/N)	S1 flower strip cover (%)	S2 flower strip cover (%)	S3 flower strip cover (%)
<i>Achillea roseoalba</i>	Y	12		0.5
<i>Anisantha sterilis</i>	N			1
<i>Anthemis arvensis</i>	Y	1		
<i>Centaurea cyanus</i>	Y	25		
<i>Centaurea nigrescens</i>	Y	2		
<i>Cichorium intybus</i>	Y	8	40	25
<i>Convolvulus sepium</i>	Y		2	5
<i>Cynodon dactylon</i>	N	20		
<i>Echium vulgare</i>	Y			5
<i>Elymus repens</i>	N	15	15	15
<i>Erigeron canadensis</i>	Y		5	
<i>Galinsoga parviflora</i>	Y	0.5		
<i>Leontodon hispidus</i>	Y	2		
<i>Lolium multiflorum</i>	N		2	5
<i>Malva alcea</i>	Y	0.5	5	10
<i>Plantago lanceolata</i>	Y	1	5	2
<i>Poa pratensis</i>	N	1		0.5
<i>Polygonum aviculare</i>	Y			1
<i>Potentilla reptans</i>	Y		0.5	
<i>Ranunculus acris</i>	Y	2		
<i>Rorippa sylvestris</i>	Y	5		
<i>Silene latifolia</i>	Y		25	
<i>Sorghum halepense</i>	N	6	5	5
<i>Taraxacum officinale</i>	Y	5	8	10
<i>Trifolium pratense</i>	Y			3
<i>Trifolium repens</i>	Y			10

Appendix D. Campo Calandro late season flower strip plant species relative abundance. On September 25, 2023, two 0.5 x 8 m sections of flower strip were surveyed in proximity to greenhouses S2 and S3 while a single 2 x 2 m quadrat of flower strip was surveyed in proximity to greenhouse S1. Plant species were determined according to Bartolucci et al. (2018) and Galasso et al. (2018) for vascular plants native to Italy and vascular plants not native to Italy, respectively.

Species	Entomophilous? (Y/N)	S1 flower strip cover (%)	S2 flower strip cover (%)	S3 flower strip cover (%)
<i>Achillea roseoalba</i>	Y	2	1.5	
<i>Amaranthus retroflexus</i>	N	1		
<i>Centaurea nigrescens</i>	Y	0.5		
<i>Cichorium intybus</i>	Y		2	0.5
<i>Convolvulus sepium</i>	Y			2
<i>Cynodon dactylon</i>	N	55	15	20
<i>Elymus repens</i>	N		1	1
<i>Geranium molle</i>	Y		1	
<i>Leontodon hispidus</i>	Y	0.3		
<i>Leucanthemum vulgare</i>	Y		0.3	0.5
<i>Plantago lanceolata</i>	Y	10	1.5	1.5
<i>Polygonum aviculare</i>	Y	1		
<i>Portulaca oleracea</i>	Y	0.5	25	0.5
<i>Potentilla reptans</i>	Y	0.2		
<i>Ranunculus acris</i>	Y	4		
<i>Rorippa sylvestris</i>	Y	6	1.5	
<i>Salvia pratensis</i>	Y	3	2	
<i>Setaria italica viridis</i>	N	0.8	7	15
<i>Silene latifolia</i>	Y		1.5	
<i>Sorghum halepense</i>	N	1.5	0.5	0.5
<i>Taraxacum officinale</i>	Y	3	0.2	10
<i>Trifolium repens</i>	Y	2.5	0.5	0.1

*Appendix E. Campo Calandro vegetation statistics. Surveys were conducted July 11, 2023 (early season) and September 25, 2023 (late season) within the flower strips planted along the southern end of each greenhouse.*

Adjacent greenhouse	S1	S2	S3
Nearest pan traps	S1-A6, S1-B6	S2-A6, S2-B6	S3-A8, S3-B8
Dimensions (m)	2 x 2	0.5 x 8	0.5 x 8
<i>July 11, 2023</i>			
Species present	16	11	15
Average plant height (cm)	40	60	50
Total cover (%)	100	100	100
Total forb cover (%)	22.5	0	10
Total entomophilous species cover (%)	64.5	47.5	55
<i>September 25, 2023</i>			
Species present	16	15	11
Average plant height (cm)	15	5	5
Total cover (%)	90	60	50
Total forb cover (%)	55.3	15.5	30.5
Total entomophilous species cover (%)	25.2	43.2	16.1