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Review

Biological Control of Aphids in Spain's Urban Green Spaces

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Abstract: Green spaces in urban areas, such as parks and gardens, provide recreational, social, and health benefits for more than half of the world's inhabitants. Arthropods in urban vegetation may cause some disruption to humans but also provide vital ecological services such as biological control and pollination. However, little is known about the ecology of urban pests, their natural enemies, and how to manage them in an ecofriendly manner, especially in Southern Europe. In this review article, we consider the information available concerning the biological control of aphids in the urban green areas of Spain, mainly focusing on the different aphid species, their natural enemies (and how to enhance them), and the sampling methods used to study them. A wide range of aphid species is found in Spain, but only a few are responsible for the majority of damage (so-called k-aphids, most of which are holocyclic species), and these show two distinct injury profiles (short and long) that determine monitoring and control strategies. Urban aphids have numerous natural enemies, including more than 20 species of ladybeetles, as well as predatory hoverflies, midges, lacewings, bugs, and other groups. More than 40 species of aphid parasitoids and their tritrophic aphid plant associations have been reported. The availability and usefulness of commercially reared aphid natural enemies is discussed, and two methods to enhance natural enemies are described. We also review aphid sampling methods developed for urban green spaces. The studies provide basic information on the ecology of aphids to support conservation biological control as a reliable strategy in the urban green areas of Spain.

Keywords: conservation biological control; aphid natural enemy associations; predators; parasitoids; sampling; service plants; coccinellids; invasive species

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1. Introduction

More than half of the world's population currently resides in urban areas and that proportion is expected to increase [1]. Green spaces in urban areas include parks, gardens, and roadside trees. These are important for the well-being of urban citizens, improving their quality of life by providing ecological, economic, social, recreational, and health benefits [2,3]. Green spaces also play an important role in the conservation and sustainability of plant and animal biodiversity in anthropic ecosystems [4–6]. However, the vegetation in urban green spaces is often rich in non-native species, sometimes not well adapted to the local conditions. Both native and non-native plants face unsuitable environmental conditions (pollution, elevated temperatures, an insufficient water supply, impervious surfaces, and disrupted nutrient cycles) that cause stress and make plants more susceptible to pests, affecting their survival, functionality, and aesthetics more than in the wild [7]. Additionally, some pests can also disrupt human activities, either directly (e.g., bites and allergies) or indirectly through their products, such as honeydew excretions [8].

Pest control in urban areas has mainly been achieved using chemical pesticides. However, given the effects of such pesticides on the environment and human health, the European Commission issued Directive 2009/128/CE (sustainable use of pesticides), which imposes obligations on all Member States for pest control in agriculture and in urban green areas. Following the principles of integrated pest management (IPM) [9,10], the use of chemical pesticides should be the last resort for pest control and other (especially preventive) methods should be prioritized, including biological control.

Plant diversity and structural complexity in urban ecosystems may be greater than in adjacent natural habitats [7,11]. Multiple plant species live together in a relatively small space and may be affected by different herbivores, which in turn may have common or distinct natural enemies. But information on the trophic dynamics of plants, pests, and natural enemies in urban ecosystems is still scarce, and more studies are required to determine the optimal biological control strategies [12].

Biological control is the use of natural enemies to reduce pest populations below injury thresholds [13,14]. It can be applied as a preventive method, known as conservation biological control (CBC), where existing natural enemies are enhanced to improve their activities [15]. Biological control may also be applied as a cure using classical augmentation or inundation methods involving the mass release of natural enemies that have been commercially reared in specialized laboratories [14,16,17].

Biological control in urban green spaces mainly involves the release of commercially reared natural enemies. In Spain, it is common to release predators and parasitoids of aphids, mites, or mealybugs. The current worldwide tendency in green spaces is to apply CBC [12] rather than augmentation or inundation. However, there are fewer commercially reared natural enemies than naturally occurring enemy species, and the former tend to be expensive. The industry also focuses on crop pests rather than pests infesting urban green spaces. Because CBC is based on the use of natural enemies already established in the area affected by the pest, commercially reared enemies are not needed. Biological control in urban green spaces is challenging, and the functioning urban ecosystem must be understood in detail. In addition, pests must be identified accurately to at least the species level so that the complex of natural enemies and their associations with pest species can be exploited to maximize the survival, development, and reproduction of natural enemies, thus targeting pests effectively.

Aphids (Hemiptera: Aphididae) are among the most common pests of urban green areas in Spain [18]. They mainly cause aesthetic and comfort injuries by excreting honeydew on ornamental trees and shrubs in cities [8]. Aphids were one of the first types of pest targeted by biological control in Spain. However, they have been treated as a generic group, and predators and parasitoids were selected without considering their suitability and/or compatibility with the aphid species. Only a limited number of aphid natural enemies are commercially available in Spain (Table 1), and most releases have involved *Adalia bipunctata* (L.) or *Aphidius colemani* Viereck, the results of which are discussed below.

The first step in effective biological control is to determine which plant species are most prone to attack by aphids (k-plants) and which aphid species are responsible (k-aphids). This allows the design of new urban spaces to prevent aphid infestation. However, this approach is unhelpful when the plants are already growing in parks or street alignments. In this scenario, k-plants should be managed in a way that does not favor the k-aphid population, such as severe or drastic pruning. The second step is to determine the k-aphid population dynamics on the k-plants. It is also necessary to identify which natural enemies of aphids are present, their associations and interactions with aphids, and how they are affected by the surrounding conditions, so that they can be fostered in different urban space environments. Finally, it is also necessary to assess the success of the applied control strategies, which means a suitable monitoring strategy is required.

To improve our knowledge of aphid ecology in the urban green areas of Spain, the Entomology and Integrated Pest Management group of the University of Lleida initiated studies in the early 2000s on aphid species identification, their biology and ecology, and appropriate sampling methods. This information is necessary for the implementation of effective biological control. In this review article, we summarize the results of this 25-year study, focusing on the aphid species that were found, their associations with plants, and the seasonal abundance and life cycle of the k-aphids; the natural enemies associated with aphids and changes in their relative abundance; the analysis of habitat management to improve the impact of natural enemies; and recent advances in sampling methods.

Table 1. Natural enemies of aphids that are commercially available in Spain and can be used for biological control in urban green spaces.

Group	Order	Family	Species
Predators	Hemiptera	Anthocoridae	*Anthocoris nemoralis* (F.) *Orius majusculus* (Reuter) *Orius laevigatus* (Fieber)
	Neuroptera	Chrysopidae	*Chrysoperla carnea* Stephens group
		Hemerobiidae	*Micromus angulatus* (Stephens)
	Coleoptera	Coccinellidae	*Adalia bipunctata* (L.) *Hippodamia variegata* (Goeze) *Propylea quatuordecimpunctata* (L.) *Coccinella septempunctata* L. *Scymnus nubilius* Mulsant
	Diptera	Cecidomyiidae	*Aphidoletes aphidimyza* Rondani
		Syrphidae	*Sphaerophoria scripta* L. *Sphaerophoria rueppelli* Wiedemann *Episyrphus balteatus* De Geer *Eupeodes corollae* F.
Parasitoids	Hymenoptera	Braconidae–Aphidiinae	*Aphidius colemani* Viereck *Aphidius ervi* Haliday *Aphidius matricariae* Haliday *Lysiphlebus testaceipes* (Cresson)
		Aphelinidae	*Aphelinus abdominalis* Dalman

2. Aphid Species

The trees, shrubs, and herbaceous plants of urban green spaces in Spain are home to 157 species or genera of aphids, leading to 431 aphid–plant associations (Table S1). The aphid number includes two members of the family Adelgidae and one of the family Phylloxeridae, which are included along with Aphididae in the superfamily Aphidoidea. The aphid species with the highest number of plant associations were *Aphis fabae* Scopoli (53), *Aphis spiraecola* Patch (46), *Aphis gossypii* Glover (38), and *Aphis craccivora* Koch (27). However, these species have a limited impact on vegetation, except *A. craccivora* on some legume trees and shrubs and *A. gossypii* on *Catalpa bignonoides*, *Punica granatum,* and *Hibiscus* spp. The aphid–plant associations with the highest impact are listed in Table 2.

Table 2. Aphid–plant associations with a major damage impact in Catalonia and Spain. Aphid species names follow [19].

Aphid	Plant
Eucallipterus tiliae L.	*Tilia* spp.
Chaitophorus spp.	*Populus* spp.
Cinara cedri Mimeur	*Cedrus* spp.
Illinoia liriodendri Monell	*Liriodendron tulipifera*
Aphis gossypii Glover	*Catalpa bignonoides* *Hibiscus syriacus*
Monelliopsis caryae Monell	*Juglans nigra*
Hoplocallis pictus Ferrari	*Quercus ilex*

Table 2. *Cont.*

Aphid	Plant
Myzocallis walshii Monell	*Quercus rubra*
Aphis nerii Boyer de Fonscolombe	*Nerium oleander*
Aphis craccivora Scopoli	*Robinia pseudoacacia* *Spartium junceum* *Sophora japonica*
Periphyllus spp.	*Acer campestre*

We also found five species that had not been reported previously in the urban green areas of Catalonia or Spain (Table 3).

Table 3. New aphid species recorded in the urban green areas of Catalonia from 2000. Names of species and subfamilies follow [19,20].

Aphid	Subfamily	Host Plant	Year
M.yzocallis walshii Monell	Myzocallinae	*Quercus rubra*	2004
Drepanaphis acerifoliae (Thomas)	Drepanosiphinae	*Acer saccharinum*	2006
Monelliopsis caryae (Monell)	Myzocallinae	*Juglans nigra*	2008
Illinoia liriodendri (Monell)	Aphidinae–Macrosiphina	*Liriodendron tulipifera*	2010
Siphonatrophia cupressi (Swain)	Aphidinae–Aphidini–Aphidina	*Cupressus macrocarpa*	2012

Studies of aphids in urban ecosystems are scarce, and most of them deal with specific aphid–host plant cases [21–24]. A few studies describe aphid complexes in city vegetation, but most focus on Central [25–27] and Southeastern Europe [28] or Turkey [29]. Data reported from Western Europe are scarce and from specific moments, covering one or a few summer seasons and one city [30,31]. In this review, we provide for the first time information from a wide area and period from Western Europe.

The analysis of aphid complexes and their host plant associations reveals that many species live in the urban green areas of Spain and that many ornamental plants host aphids. A similar diversity was found in Central and Southeastern Europe and Turkey [25–29]. The list of aphids found in Spain is not final, and more associations may be identified in the future, especially for polyphagous species of the genus *Aphis*.

Some of the most common polyphagous species (such as *A. gossypii* and *A. spiraecola*) have also been reported in other regions of Spain [31], but this is not the case for some of the most injurious species, such as *Eucallipterus tiliae L.*, *Monelliopsis caryae* (Monell), and *Illinoia liriodendri* (Monell). This reflects the host-specificity of these species, because the composition of urban green areas varies between cities. Despite the wide range of species complexes, most damage is caused by a small number of species. The aphid species repeatedly found year after year and that excrete profuse quantity of honeydew and cause serious comfort damage were qualified as k-species. The identification of these problematic k-aphid species facilitates the design of green spaces to avoid pest infestation. Given the diversity of vegetation, including non-native ornamental species, city vegetation is prone to infestation by exotic insects.

3. Seasonal Abundance and Life Cycle of K-Aphid Species

Aphid annual life cycles have been characterized by monitoring public parks, gardens, and tree alignments affected by the k-species from early spring to late autumn [18,24,32]. The highest abundance period varied according to the aphid–plant association. It was possible to distinguish two types of phenology (Figure 1):

(1) Species with a short period of maximum abundance, lasting approximately one month. Examples included *Hoplocallis pictus* on *Quercus ilex*, *Periphyllus hirticornis* (Walker) on

Acer campestre, *Phorodon humuli* (Schrank) on *Prunus cerasifera* Pisardii, *E. tiliae* on *Tilia* spp., and *Myzocallis walshii* on *Quercus rubra* (Figure 1A);

(2) Species with a period of high abundance lasting two months or more. Examples included *A. gossypii* on *Hibiscus syriacus*, *A. craccivora* on *Robinia* spp., *Chaitophorus populialbae* (Boyer de Fonscolombe) on *Populus* spp., *M. caryae* on *Juglans nigra*, and *I. liriodendri* on *Liriodendron tulipifera* (Figure 1B).

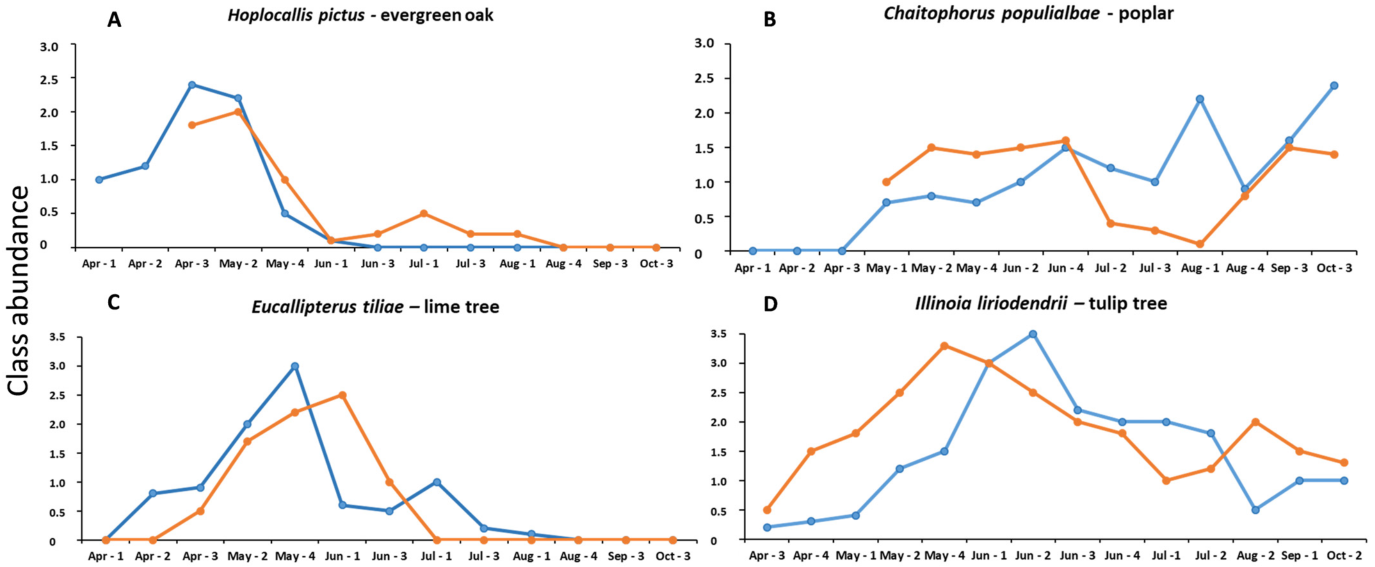

Figure 1. Seasonal abundance of some common aphid species on their host plants. (**A**,**B**) Species with short abundance period. (**C**,**D**) Species with long abundance period. Reproduced with permission [20,21,26].

The duration of injury periods must be known to ensure the sampling method is suitable and to determine the optimal control strategies. As shown for *E. tiliae* [33], a holocycle was clearly observed for other species of Myzocallinae, such as *M. walshii* and *M. caryae* [32,34]. A holocycle was also observed for the Drepanosiphinae species *Drepanaphis acerifoliae* [35] and for the Macrosiphini species *I. liriodendri* [24]. However, although *Siphonatrophia cupressi* is a monoecious holocyclic species in its American region of origin and was observed on the tips of *Cupressus macrocarpa* branches in the early spring, no sexual morphs were observed in Catalonia, despite the record of oviparous females and absence of males in France [36].

No sexual morphs of *A. fabae* were observed, although its subspecies are also holocyclic on the European spindle tree and other primary host plants [19]. This may reflect incomplete or inaccurate sampling during autumn. No sexual morphs or eggs were reported for *A. craccivora*, *A. spiraecola,* or *A. gossypii*. These species are anholocyclic elsewhere and in Europe [19]. However, *A. gossypii* oviparae and males were collected on catalpa trees from different locations in Catalonia, suggesting catalpa is the primary host, as reported in Asia [37,38] and North America [39]. Some records in Europe report holocyclic *Aphis catalpae* Mamontova on catalpa trees [40,41], but this species was not found in Spain according to the Fauna Iberica reference book [42], and the only record is from Valencia [31]. The mitochondrial COI and COII sequences of *A. catalpae* and *A. gossypii* show a high similarity [41]. Further molecular studies could provide more insight into the aphid catalpa populations in Spain and other geographic regions.

4. Aphid Predators

Most studies of aphid predators in Spain's urban green spaces have focused on ladybeetles [43,44], which are common aphid predators found in urban ecosystems [45,46] and are the most common aphid predators recorded in Spain. Twenty-three species or genera have been recorded, most of them on trees and shrubs, but their relative occurrence varies considerably (Table 4).

Table 4. Ladybeetle species associated with aphids in urban green landscapes of Spain, their relative occurrence on a scale of 1 (rare) to 5 (very common), and their vegetation habitat by order of occurrence (T = trees, S = shrubs, H = herbs).

Ladybeetle Species	Relative Occurrence	Habitat
Adalia bipunctata (L.)	5	T, S
Adalia decempunctata (L.)	4	T, S
Anatis ocellata (L.)	1	T
Calvia quatuordecimguttata (L.)	2	T
Coccinella septempunctata L.	4	H, S, T
Coccinula quatuordecimpustulata (L.)	2	H
Exochomus quadripustulatus L.	3	T, S
Harmonia axyridis (Pallas)	5	T, S
Harmonia quadripunctata (Pontoppidan)	3	T
Hippodamia variegata (Goeze)	4	H, S, T
Hyperaspis sp.	2	T
Myzia oblongoguttata (L.)	1	T
Myrrha octodecimguttata L.	3	T
Oenopia conglobata (L.)	5	T, S
Oenopia doublieri (Mulsant)	2	T
Oenopia lyncea (Olivier)	2	T, S
Platynaspis luteorubra (Goeze)	2	S, T, H
Propylea quatuordecimpunctata (L.)	3	H, S, T
Scymus apetzi Mulsant	4	T, S
Scymnus interruptus (Goeze)	4	T, S
Scymnus sp.	5	T, S
Sospita vigintuguttata (L.)	1	T
Vibidia duodecimguttata (Poda)	1	T

Currently, the most abundant species are *Adalia bipunctata* (L.), *Harmonia axyridis* (Pallas), and *Oenopia conglobata* (L.), and the genus *Scymnus*. *Hippodamia variegata* (Goeze) was the only species to prey and reproduce on oleanders, probably because the aphid *Aphis nerii* Boyer de Fonscolombe is toxic to most of the recorded coccinellid species, except *H. variegata* [47].

The abundance of ladybeetles in the study area has been reported before [43,44], including the prevalence of *O. conglobata*, especially on trees. This species prefers some of the most abundant aphid pests in Catalonia, and thus has potential as a commercial biocontrol agent [48]. Furthermore, we have reported studies to improve the rearing of this species in our laboratory [49]. However, this natural enemy is not currently produced commercially in Spain.

Adalia bipunctata is the only commercially produced ladybeetle species available for urban green spaces (Table 1). The regular release of this species has induced changes in ladybeetle prevalence, including the displacement of *O. conglobata* in some localities of Catalonia [50]. However, the most remarkable change in the relative abundance of ladybeetle species in Spain reflects the expansion of the invasive species *H. axyridis* [50], which threatens to displace native species [51]. Following the failed introduction of *H. axyridis* in the south of Spain for the control of aphids in greenhouses, records of its occurrence in other regions began in 2007, with the first overwintering aggregations (confirming its establishment) reported in 2013 [50]. Since then, *H. axyridis* has expanded to the northeastern part of the Iberian Peninsula, where it has become prevalent in many green spaces [50]. The preference of *H. axyridis* for urban areas has been described in other West Palearctic countries [52–54]. The results in our study region showed that the native ladybeetle most at risk is *A. bipunctata* [50], as reported in other countries [51,55–57]. This seems to reflect the overlapping habitat of the two species, with *H. axyridis* prevailing due to its faster development, greater voracity, its production of substances toxic for other ladybeetle species, and the greater efficiency of its immune system against pathogens, which enhance its performance [50,58–60].

One of the limitations of ladybeetles in augmentative biological control programs is the application strategy [61]. In a trial performed in Central Catalonia, where *A. bipunctata* was released for the control of the tulip tree aphid, we found that aphid abundance did not differ significantly between release/non-release sites (Kruskal–Wallis test: $H = 2.08$; $p = 0.14$), and the relative abundance of the ladybeetle was not significantly higher at the release site vs. non-release sites (Kruskal–Wallis test: $H = 3.42$; $p = 0.064$) and was in fact even lower, suggesting that released individuals move to other sites searching for more favorable resources, and this is not determined solely by aphid abundance (Figure 2).

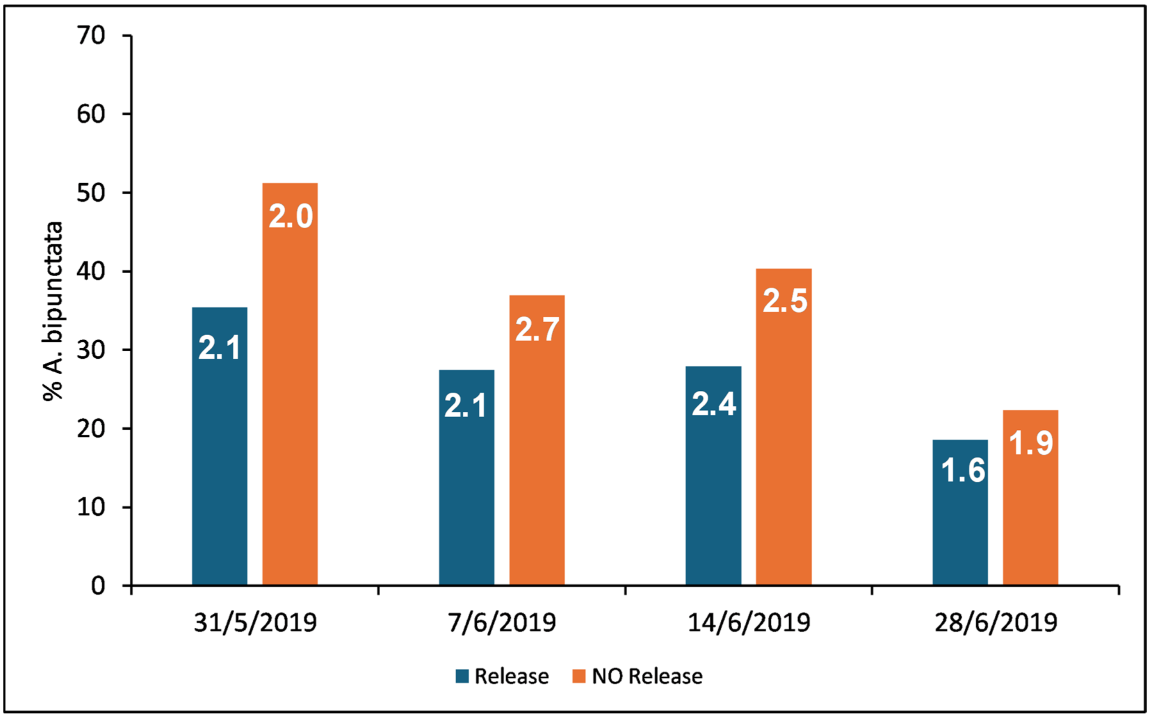

Figure 2. Relative abundance of *A. bipunctata* in the coccinellid complex on tulip trees of central Catalonia, comparing a release site (release on 8 May) with a no-release control site. Data are means of the average aphid abundance class ± standard errors.

Several studies have also reported other common predators in Spain's urban green spaces [43]. The main recorded hoverfly (Diptera: Syrphidae) species were *Sphaerophoria scripta* L., *Episyrphus balteatus* De Geer, *Eupeodes corollae* F., *Scaeva pyrastri* L., *Sphaerophoria rueppellii* Wiedemann, and the genera *Paragus* and *Melanostoma*. Larvae of *Aphidoletes aphidimyza* Rondani (Diptera: Cecidomyiidae) and *Leucopis* sp. (Diptera; Chamaemiidae) were often found to prey on aphid colonies. Green lacewings (Neuroptera: Chrysopidae), mainly the *Chrysoperla carnea* Stephens group, were more abundant than brown lacewings (Neuroptera: Hemerobiidae). Pirate bugs (Hemiptera: Anthocoridae), especially *Orius* spp.; true bugs (Hemiptera: Miridae), mainly *Daraeocoris* spp.; and big-eyed bugs (Hemiptera:

Lygaeidae) were also commonly reported. Earwigs (Dermaptera: Forficulidae), ground beetles (Coleoptera: Carabidae), rove beetles (Coleoptera: Staphilinidae), soldier beetles (Coleoptera: Cantharidae) and some other beetles were identified less frequently. Several spider families were among the most common arachnid predators of aphids, including Lycosidae, Lyniphiidae, Thomisidae, and Salticidae, as well as velvet mites (Trombidiformes: Trombididae).

5. Aphid Parasitoids

Forty-five species or genera of parasitoids were associated with aphids in urban green areas of Catalonia (Table S2). Most were aphidiinids (Hymenoptera, Braconidae, Aphidiinae), but some species of *Aphelinus* (Hymenoptera, Aphelinidae) were also identified. We recorded 181 aphid–parasitoid (175 Aphidiinae and six Aphelinidae) associations, and 267 tritrophic plant–aphid–parasitoid associations. An extensive list of these tritrophic associations, as well as the associations of aphid parasitoids with aphid subfamilies in the region, has already been published [62]. Some species were polyphagous (Table 5), including *Lysiphlebus testaceipes* Cresson, which was able to parasitize 40 aphid species and was recorded in 85 plant–aphid associations among 7 aphid subfamilies, especially Aphidinae (Aphidini–Aphidina, Aphidini–Rhopalosiphina and Macrosiphini). *L. testaceipes* showed high rates of parasitism in some of the most injurious aphids in Spanish urban areas (*A. gossypii*, *A. craccivora,* and *A. nerii*). However, *Binodoxys angelicae* Haliday also frequently parasitized the subfamily Aphidini–Aphidina. Species of the genus *Trioxys*, mainly *T. pallidus* Haliday and *T. curvicaudus* Mackauer, were the main parasitoids associated with Myzocallinae, which causes major injuries to trees. The principal associations were *E. tiliae* on *Tilia* spp., *M. caryae* on *J. nigra*, *M. walshiii* on *Q. rubra*, and *H. pictus* on *Q. ilex*.

Table 5. Number of aphid species/subfamilies and number of plant–aphid associations involving the most polyphagous parasitoid species, based on [62].

Parasitoid	Aphid Species	Aphid Subfamily	Plant–Aphid Associations
Lysiphlebus testaceipes	40	Aphidinae–Aphidina and Rhopalosiphina Aphidinae–Macrosiphini Anoecinae Pemphiginae Greniidae Myzocallinae	85
Bynodoxys angelicae	14	Aphidinae–Aphidina	32
Aphidius matricariae	14	Aphidinae–Macrosiphini	20
Lipolexis gracilis	10	Aphidinae–Aphidina	12
Trioxys pallidus	10	Myzocallinae	14

In the Northeast of the Iberian Peninsula, the most problematic aphids have specific parasitoids or a parasitoid complex associated with them, which helps to keep aphid populations below the injury threshold or to shorten the injury period. Some species of parasitoids have been widely used in augmentative biological control programs targeting aphids in European agroecosystems [16]. Four Aphidiinae and one Apelinidae species (*Aphelinus abdominalis*) are commercially available in Spain. *A. colemani* has frequently been released for the control of aphids in the urban green spaces of Spain, but we have collected few aphid colonies parasitized by this species, suggesting some environmental conditions in the Mediterranean region may not support this parasitoid. Whereas the main parasitoid species of *A. nerii* in Malta is *A. colemani* [63], in our region it is *L. testaceipes* [47]. This last parasitoid, exotic for Europe but now considered "as native" (naturalized), is widely found in Spain's urban green spaces, confirming its ability to become established in different habitats in distinct geographical areas from the coast to inland Spain, suggesting it would be useful as an aphid control agent in green spaces [62].

6. Studies to Enhance Natural Enemies

The main cause of mortality for natural enemies is the chemical pesticides used against pests. This can be addressed by reducing or eliminating the use of such pesticides or switching to those with less impact against natural enemies. However, the managers of urban green spaces, and citizens, are reluctant to abandon pesticides. To demonstrate the effectiveness of biological control, two of the authors (B.L. and X.P.) carried out an experiment in the city of Lleida (Western Catalonia), where streets planted with the American oak (*J. nigra*) are every year severely infested by the aphid *M. caryae*. This was a 3-year experiment (2011–2013) where chemical pesticides were replaced with *Ephestia kuehniella* Zeller eggs and honey diluted in water (food suitable for ladybeetles and other common predators, such as *Orius* spp.) on 20 trees (10 per side) in one street. The abundance of aphids and natural enemies was recorded and compared with trees on another street, where pesticides remained in use.

The yearly maximum infestation in the conventionally managed street from 2008 to the end of the experiment is compared to the experimental trees in Figure 3, which also shows the number of days with *M. caryae* populations above the injury threshold (average class 2). In the trees under conventional management, infestation levels were always high, and the number of days above the injury threshold usually exceeded 30. In contrast, although the infestation level was initially above the threshold in the experimental trees, the aphid population declined gradually, and the number of days above the threshold was lower. After three seasons without insecticide treatments, infestation approached near tolerable levels, and the number of days above the injury threshold was reduced by 50%. The number of aphid predators increased notably from 2011 to 2013 in untreated trees. These results show that CBC strategies work over the medium to long term rather than showing immediate benefits, as previously reported [64], and support the current trend toward green spaces free of pesticides. It would be very interesting to repeat a similar, or even longer, experiment in other urban conditions or regions to improve reliability.

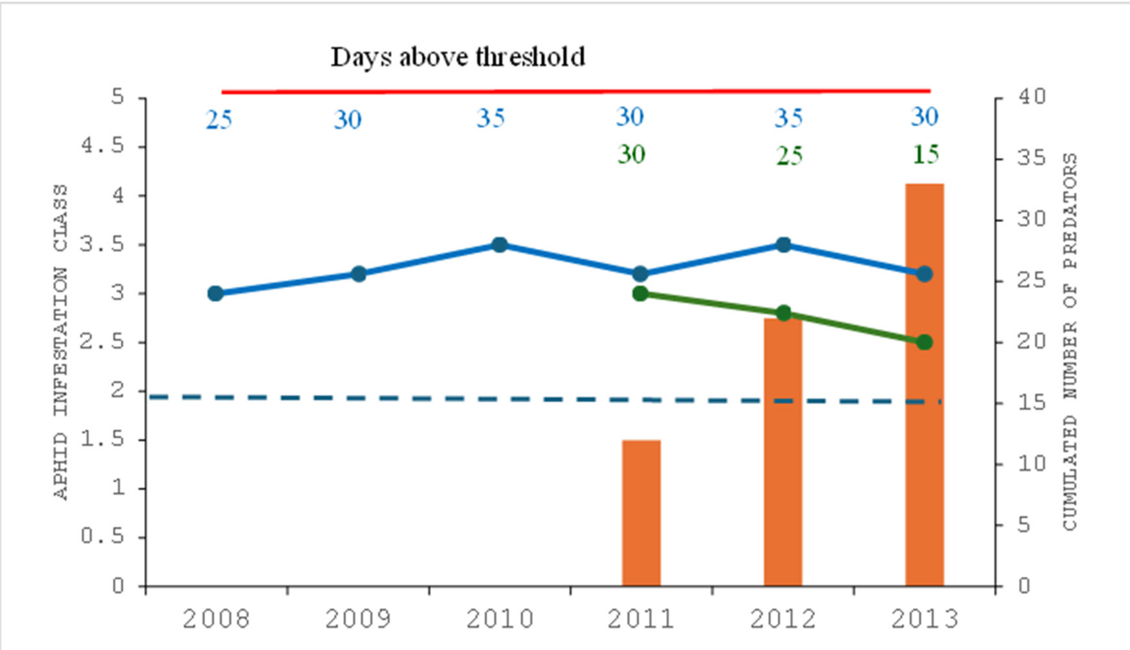

Figure 3. Infestation levels of *M. caryae* on *J. nigra* trees in Lleida conventionally managed (blue line) with insecticide treatments (2008–2013) or untreated and provided with food for natural enemies (2011–2013) (green line). The dotted blue line shows the injury threshold for this aphid. The annual number of days (below the red line) with aphid infestation above the threshold (blue colour for conventionally managed trees, green colour for untreated trees) is also shown, along with the abundance of natural enemies on untreated trees.

Increasing biodiversity in urban spaces is another way to enhance the suppression of pests by natural enemies. *Stephanitis pyroides* (Scott) (Hemiptera: Tingidae) was extremely abundant in simple landscapes and rare in complex ones, where the vegetation was in different strata (ground cover, herbaceous plants, shrubs, understory trees, and overstory trees) [65–68]. In a study conducted in the UK [30], the abundance of some species of ladybirds was positively associated with increased garden plant diversity but negatively affected by impervious surfaces. In the same study, the abundance of hoverflies was also positively associated with flowering plant diversity, probably because adults feed on pollen and nectar. The introduction of plants with different flowering periods, also known as service plants, is a practice that has been implemented in many cities to enhance ecosystem services. Besides the aesthetic benefits, this approach attracts some beneficial insects and suppresses some pests. Service plants have been used to enhance the biological control of various pests of ornamental plants [67,68], but aphids have been largely overlooked. A 4-year study determined the effect of flowering service plants on the abundance of *A. nerii* infesting oleanders [47]. Plots surrounded by these plants supported smaller aphid populations and featured more predators and mummified aphids. The authors concluded that the inclusion of service plants with flowering periods that overlap with the oleander aphid infestation can contribute to the CBC of *A. nerii* in the Mediterranean region, where oleanders are planted along fences, on roundabouts, and in small islands in public gardens.

Some practices that may enhance predators and parasitoids of aphids may also increase their natural enemies, especially hyperparasitoids. Although several species of aphid hyperparasitoids have been reported in green spaces of Spain [36,69], their interference in biological control process has not been assessed.

7. Aphid Sampling Procedures

The main problems attributed to aphids in urban areas are comfort injuries caused by the excretion of honeydew. Unlike the economic criteria for agriculture and commercial forestry, comfort damage is difficult to quantify because it depends on the demands and perception of citizens. To determine comfort–injury thresholds, it is necessary to obtain quantitative information on insect abundance.

Monitoring is a basic component of IPM for aphids in urban green areas, and two main methods have been applied. Aphids can be directly measured by counting the number of individuals on a defined sampling unit (e.g., a certain number of leaves or a segment of a branch), but this is laborious and time-consuming. An easier method is to measure honeydew dripping onto yellow water-sensitive cards. This method also has some limitations, because it is affected by weather and the humidity of the leaves, branches, or even the soil supporting the displayed cards.

We developed a method that uses levels of abundance to evaluate aphid infestation, as first reported for *E. tiliae* [33] but later for other aphids and their hosts plants [24,32,47,70]. This method is now used by many pest control managers in the urban green spaces of Catalonia and Spain [31,71,72]. The method involves a visual inspection of the tree canopy at low and medium heights (Figure 4). Aphid abundance is then ranked according to a categorical scale from 0 (absence of aphids) to 4 (large colonies) (Table 6a). In some cases, the scale may be modified by adding an extra class and considering the percentage of occupied leaves (Table 6b). For shrubs, the same approach is used for the assessment of branch tips.

This sampling method revealed a close correlation between the average infestation level and the quantity of honeydew dripping from the tree (Figure 5) [18,32,33]. However, averaging abundance classes, when they are represented as categories without a consistent numerical relationship between them (for example, class 2 does not represent twice the abundance of class 1), may underestimate the number of cases where honeydew dripping is present. In a recent study [24], where the infestation level at which honeydew dripping started was determined, the class average was changed by the absolute frequency of abundance classes that suppose honeydew dripping, resulting again in a close correlation (Figure 6).

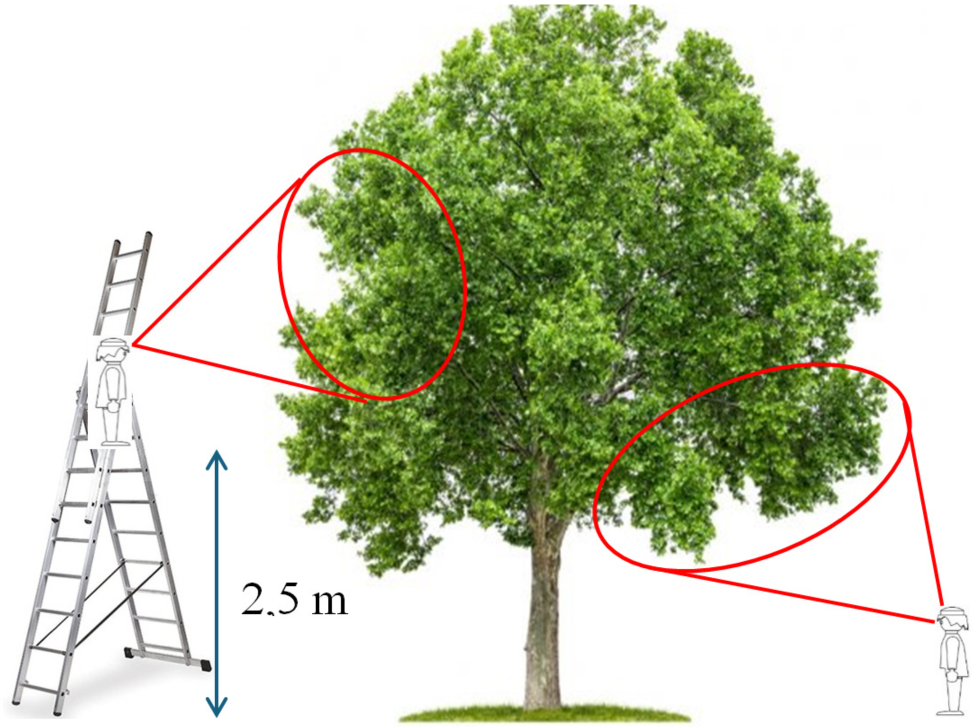

Figure 4. Position of observers to determine aphid abundance and allocation of scores on a scale of 0–4 or 0–5 (Table 6). If a ladder cannot be used, samples can be acquired using a pruning pole.

Table 6. Severity of aphid infestation on tulip trees according to (**a**) the original scale of 0–4 and (**b**) the modified scale of 0–5.

(a) Original Scale		
Class	**Aphid Infestation**	
0	No aphids	
1	Presence of isolated individuals	
2	Small colonies	
3	Medium colonies	
4	Large colonies	
(b) Modified Scale		
Class	**Infestation**	**Characteristics**
0	Null	Absence of aphids
1	Presence	Isolated individuals or small colonies on some leaves of the sampling unit
2	Low	Small colonies on a few leaves (<25%)
3	Medium	Small or medium colonies on some leaves of the sampling unit (25–50%) and some honeydew
4	High	Medium or large colonies on some or many leaves of the sampling unit (50–75%) and abundant honeydew
5	Very high	Large colonies occupying nearly all the leaves of the sampling unit (>75%) and highly abundant honeydew

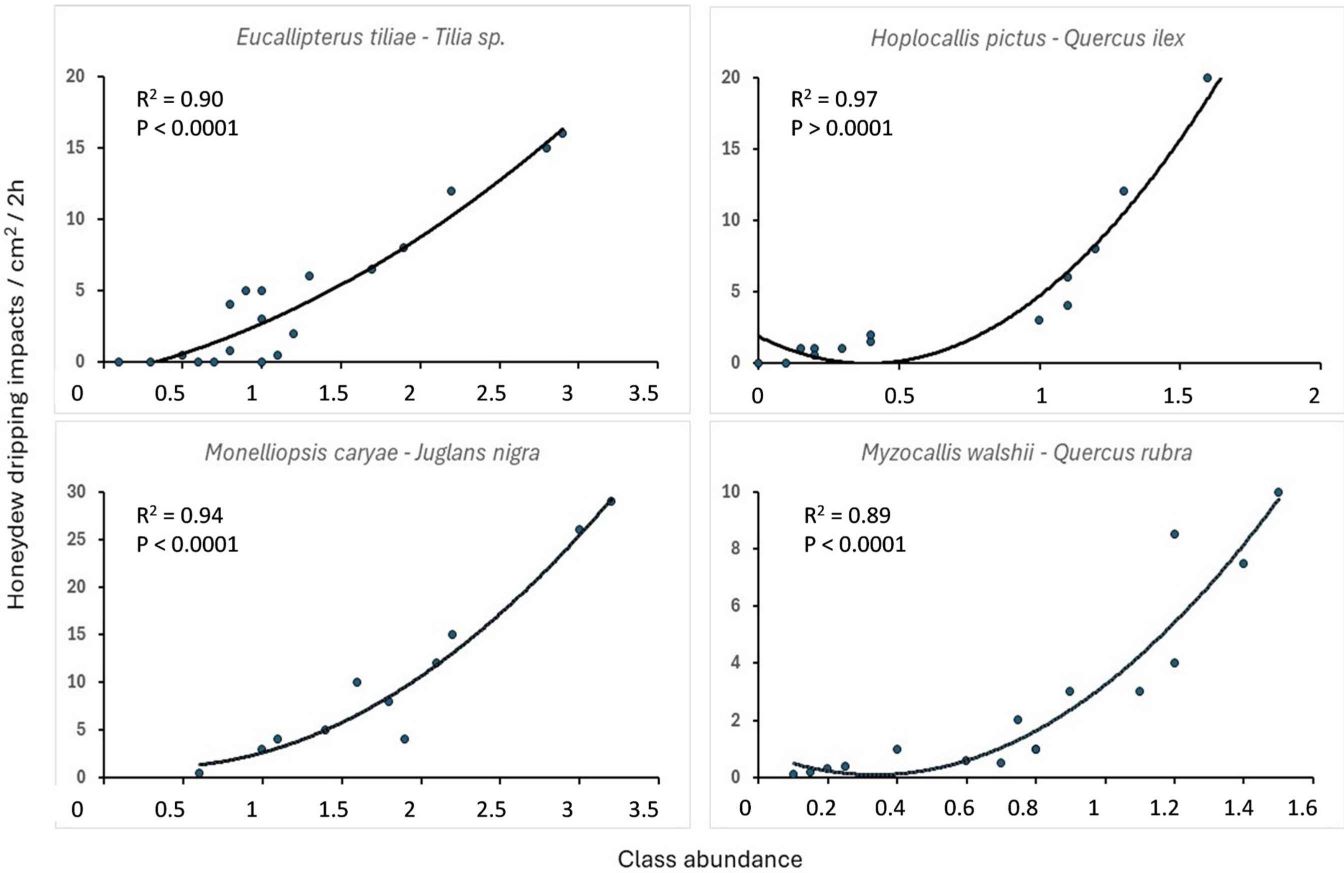

Figure 5. Relationships between the class abundance average and honeydew dripping. Adapted from [18,32,33].

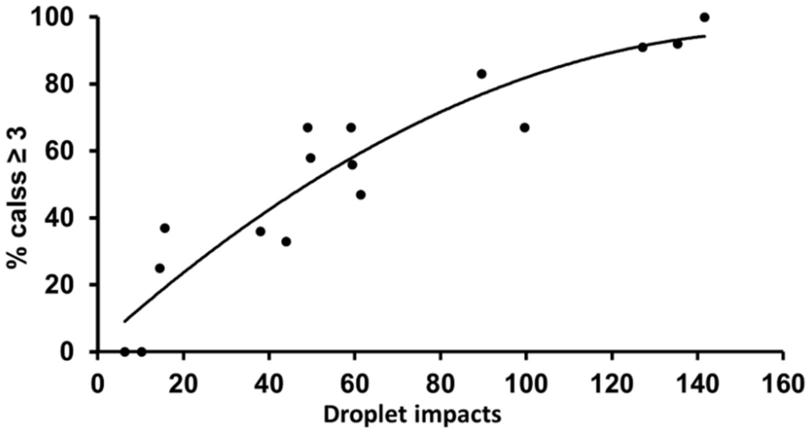

Figure 6. Correlation between the average number of honeydew droplets recorded on yellow water-sensitive cards for 2 h and the severity of *I. liriodendri* infestation $\geq$ class 3 on tulip trees (R^2 = 0.88; F = 47.70; $p < 0.001$) [24].

In summary, the sampling method we developed is an easy way to determine aphid abundance and comfort injuries, facilitating decisions that can be adapted to the characteristics of each aphid–plant association and green space. It can be applied by anyone after brief training, it saves time, and it allows sampling in more green spaces than other methods. Despite the usefulness of this sampling method, its use may have certain restrictions. For example, it is difficult to observe very tall trees or, even, the upper parts of the tree canopy in medium-sized trees; wind can make it difficult to easily see the level of infestation; and heavy rain and high temperatures can encourage aphids to hide in more protected parts of the vegetation and lead to underestimations

8. Final Considerations

The studies in Catalonia and other parts of Spain that are presented in this review article provide essential information to improve our knowledge of aphid ecology in urban green spaces. The results have identified the associations between k-aphids and their host plants, as well as characterizing their life cycle and population dynamics. This information will allow the design of new urban spaces to prevent aphid infestations or the management of vegetation to discourage aphid populations.

Aphid natural enemy surveillance has shown the wide range of aphid predators and parasitoids found in urban green spaces in Spain. This is likely to be true in other parts of Europe, as reported for parasitoids in Southeastern European countries [28]. It seems well justified to enhance such populations for CBC programs against aphids, especially when other strategies are limited by the number of commercially available biological control agents. The cessation of pesticide treatments reduces aphid-induced injuries to plants in the medium term, probably by allowing natural enemies to flourish. Service plants can contribute to the reduction of aphid populations on oleanders. But these experiments provide only preliminary information, and more studies are required to determine optimal strategies that (1) enhance natural enemy populations in different urban environments and (2) determine the most appropriate service plants and how to display and to manage them in green spaces, considering the stratification of vegetation and landscape features [12,73–76].

The development of sampling methods that save the labor and time of people that manage urban green spaces is necessary for the implementation of IPM. The sampling method described in this review has facilitated the acquisition of information on aphid populations before and after the application of control strategies. However, sampling methods must be adapted to the characteristics of specific locations to ensure they can be applied consistently and accurately.

We have focused on biological control and the suitability of natural enemies, mainly aphid predators and parasitoids. However, biological control agents should be used with care, considering any potential effects on urban ecosystems. The indiscriminate application of biological control agents, such as the introduction of exotic natural enemies, can threaten native or naturalized natural enemies. Urban green spaces are prone to invasion by exotic species, and aphids and their natural enemies are no exception. The most remarkable example of an exotic aphid predator is *H. axyridis*, which originates from Asia. This ladybeetle can adapt to diverse environments, where it competes with autochthonous ladybeetle species and displaces them [53,77], as observed in Catalonia since 2013 [50]. Despite its ability to consume aphids voraciously, the commercial production of *H. axyridis* is not allowed in Europe or America due to the ecological damage it causes. Although in many countries *H. axyridis* has expanded into different agroecosystems, it seems to prefer initial establishment in urban green spaces, as reported in Catalonia [50]. Because the eradication of this species is impracticable, we must adapt to its presence and refrain from actions that facilitate greater expansion.

Another exotic natural enemy is the aphid parasitoid *L. testaceipes*, which originated from Cuba and was introduced into the Mediterranean region for the control of citrus pests [78]. This parasitoid has expanded from the coast of the Iberian Peninsula to inland regions and has become the most abundant parasitoid species in Spain's urban green areas [43,62,79]. *L. testaceipes* is produced commercially in several European countries, including Spain, because it is considered naturalized. *L. testaceipes* was able to parasitize *S. cupressi*, a new aphid species from North America that we found in Spain for the first time in 2015 [36].

CBC in urban green spaces is not a simple task. It requires time and knowledge to be implemented. Its control efficiency is not immediate, and effects are delayed. However, its role in controlling pests in green spaces is more and more relevant in Europe because of the restrictions in use of pesticides in cities and urban areas. CBC is an ecofriendly approach that may contribute to the current drive towards "phyto zero", the elimination of all chemical pesticide treatments. In addition to entomologists, pest control advisors, and managers, urbanists and council governors should play a role in designing and maintaining green spaces, ensuring an integrative view of the problems. The concerns of citizens about the care of green spaces should also be considered, especially in Southern European countries. Reliable research data, as we have presented in this article on aphids, are basic, but so also is the transfer of results to stakeholders. Moreover, a cost/benefits analysis and education are needed to convince citizens and city administrators of the benefits of this control strategy. A cost/benefit analysis, inexistent until now for urban green areas of Spain, is difficult to perform and to generalize, because it depends on many local factors. Such a type of analysis needs to deal with not only chemical control but other methods of biological control.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su162411225/s1, Table S1: Aphid species (in alphabetical order) reported in urban green areas of Spain and aphid–host plant associations. Table S2: Aphid parasitoid species, number of associations with aphids, and number of tritrophic plant–aphid–parasitoid interactions.

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