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Original article (Orijinal araştırma)

The diversity and host interactions of aphids (Hemiptera: Aphididae) on different plant communities in an urban ecosystem[1]

Kentsel bir ekosistemde farklı bitki komüniteleri üzerindeki afitlerin (Hemiptera: Aphididae) çeşitliliği ve konukçu bitki etkileşimleri

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Abstract

The aim of this study was to reveal the diversity and host interactions of aphids on different plant communities in an urban ecosystem in the northwest of Türkiye between April and October from 2021 to 2022. From the sampling, 55 aphids from 26 genera in the family Aphididae (Hemiptera) on 65 host plant of 26 families were determined. From the aphids, *Capitophorus archangelskii* Nevsky, 1928 and *Uroleucon leontodontis* (Hille Ris Lambers, 1939) are found to be new to the aphid fauna of Türkiye. In the urban ecosystem, 108 interactions between aphids and hosts, including the new records of the interactions for Türkiye were identified on different plant communities. Also, we revealed the biodiversity of aphids and hosts interactions in various plant communities in the urban ecosystem. Our results showed that the species richness and abundance of aphids were significantly higher on the herbaceous plants compared to other communities. Also, interactions between aphids and their hosts in the herbaceous plants were more diverse than the trees and shrubs. Accordingly, the results of our study revealed that biodiversity of interactions between aphids and their hosts was higher on the herbaceous plants compared to other plant communities in the urban ecosystem.

Keywords: Aphid, diversity, host plant community, interaction, urban ecosystem

Öz

Bu çalışmada 2021 ve 2022 yıllarında Nisan ve Ekim ayları arasında kuzeybatı Türkiye'de bir kentsel ekosistemde farklı bitki komüniteleri üzerindeki afitlerin çeşitliliği ve konukçu etkileşimlerinin ortaya çıkarılması amaçlanmıştır. Örneklemelerin sonucunda 26 familyaya bağlı 65 konukçu bitki üzerinde Aphididae (Hemiptera) familyasından 26 cinse bağlı 55 afit tespit edilmiştir. Afitlerden, *Capitophorus archangelskii* Nevsky, 1928 ve *Uroleucon leontodontis* (Hille Ris Lambers, 1939) Türkiye afit faunası için yeni kayıtlardır. Kentsel ekosistemde, farklı konukçu bitki komüniteleri üzerinden Türkiye için yeni etkileşim kayıtlarını da içeren afitler ve konukçu bitkileri arasında 108 etkileşim tespit edilmiştir. Ayrıca, kentsel bir ekosistemdeki farklı bitki komüniteleri üzerindeki hem afitlerin hem de afit-konukçu etkileşimlerinin biyoçeşitlilik değerleri de ortaya çıkarılmıştır. Sonuçlarımız, afitlerin tür zenginliği ve bolluğunun yabancı otlar üzerinde diğer bitki komünitelerine kıyasla önemli ölçüde daha yüksek olduğunu göstermiştir. Benzer şekilde, yabancıotlar üzerindeki afit-konukçu etkileşimleri de ağaçlar ve çalılar üzerinde olduğundan daha fazla çeşitlilik göstermiştir. Bu doğrultuda, çalışmamızın sonuçları kentsel bir ekosistemde yabancıotlar üzerindeki afitlere ve konukçuları arasındaki etkileşimlerin biyoçeşitliliğinin diğer bitki kominitelerine göre daha yüksek olduğunu ortaya koymuştur.

Anahtar sözcükler: Afit, çeşitlilik, konukçu bitki komünitesi, etkileşim, kentsel ekosistem

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Introduction

Urban areas including parks, landscaped areas, green spaces, roadsides, green roofs, and the gardens of homes and buildings in the world are important biodiversity hotspots for many species. These areas play an important role in the conservation and sustainability of plant and animal biodiversity (Threlfall et al., 2016; Durà et al., 2023). Also, park ecosystems in urban areas can be home to many rare species, and support the population development of vulnerable species. It is widely known that the abundance and species richness of certain arthropod species change in urban ecosystems compared to their surrounding natural habitats. Plant diversity in urban ecosystems can be higher, and even more diverse than in adjacent natural habitats (Hope et al., 2003; Smith et al., 2006). Variations in host plant communities in urban ecosystems may affect the diversity of herbivorous arthropods and their abundance, species richness, host plant preference and natural enemies (Kareiva, 1983; Shrewsbury & Raupp, 2006; Bennewicz & Barczak, 2016). The diversity of plant communities is known to have a significant positive correlation with the species richness of pest insects. In addition, many studies have demonstrated that due to their richer vegetational diversity or complexity, urban ecosystems support the greater abundance or richness of natural enemies, especially predators and parasitoids with a wide variety of prey (Tooker & Hanks, 2000; Frank & Shrewsbury, 2004; Shrewsbury et al., 2004; Tomanović et al., 2006, 2009; Kavallieratos et al., 2013, 2016).

Some species described as urbanophiles show considerable success in urban ecosystems (Shochat et al., 2010). Aphids (Hemiptera Aphididae), one of the most important examples of these arthropod urbanophile species, are one of the most destructive pest insect groups in both agricultural and urban ecosystems. The common presence of aphids in urban ecosystems is supported by their cyclical parthenogenesis (Simon et al., 2002), as well as different levels of urbanisation and land cover (Barczak et al., 2021). Also, water availability gradient and vegetation diversity in urban ecosystems positively affects the increase in the abundance and breeding of aphids (Andrade et al., 2017).

It is evident that host plant communities have largely influenced the diversity of aphid species. Approximately 40% of known aphid species live on trees, with the other 55% preferring to feed on host herbaceous plants and shrubs (the remaining 5% live on unknown hosts). Some aphids, about 10% of them, have a heteroecious life cycle. In this cycle, aphids migrate to secondary hosts consisting of flowering herbaceous hosts in the summer after spending all the seasons except summer on primary hosts (Blackman & Eastop, 2006). Therefore, investigating the preferences of aphids for different host plant communities within an ecosystem is important both in terms of obtaining data on the host plant selection of aphids and in gaining a better understanding of their biology, life cycles, and management. Some studies have been carried out on aphid-host interactions on all plant communities in different areas in urban ecosystems (Borowiak-Sobkowiak & Wilkaniec, 2010; Bennewicz & Barczak, 2014; Barczak et al., 2021). However, it is clear that the data on the biodiversity of aphid-host plant interactions on different plant communities such as trees, shrubs, and herbaceous plant, needs to be collected and studied separately.

As can be understood from the above, numerous studies investigating aphid-host plant interactions in urban ecosystems have commonly focused on plant communities such as trees and shrubs in parks and landscaped areas. Based on the fact that herbaceous host plants represent an important stage in the life cycles of many aphid species, we were interested in how the biodiversity of aphid-host interactions on different host plant communities would change in all urban ecosystems including parks, landscaped areas, roadsides, and the gardens of homes and buildings. In this context, we aimed to reveal the diversity of aphid species and their host plant interactions on different plant communities such as trees, shrubs and herbaceous plants in an urban ecosystem in northwest Türkiye.

Materials and Methods

Sampling site

Our sampling area consists of the city centre of the Çanakkale Province including the central district of Kepez (Figure 1). Approximately 198,000 people live here, in an area of 12 km^2. There are also many urban areas in the Çanakkale Province, including park-landscaped areas such as Halkbahçesi Park, Sarıçay Park, the Terzioğlu Campus, Esenler Özgürlük Park, the Dardanos Campus, Osnabrück Park, street medians and roadsides, as well as the gardens of homes and buildings, which contain numerous different plant communities.

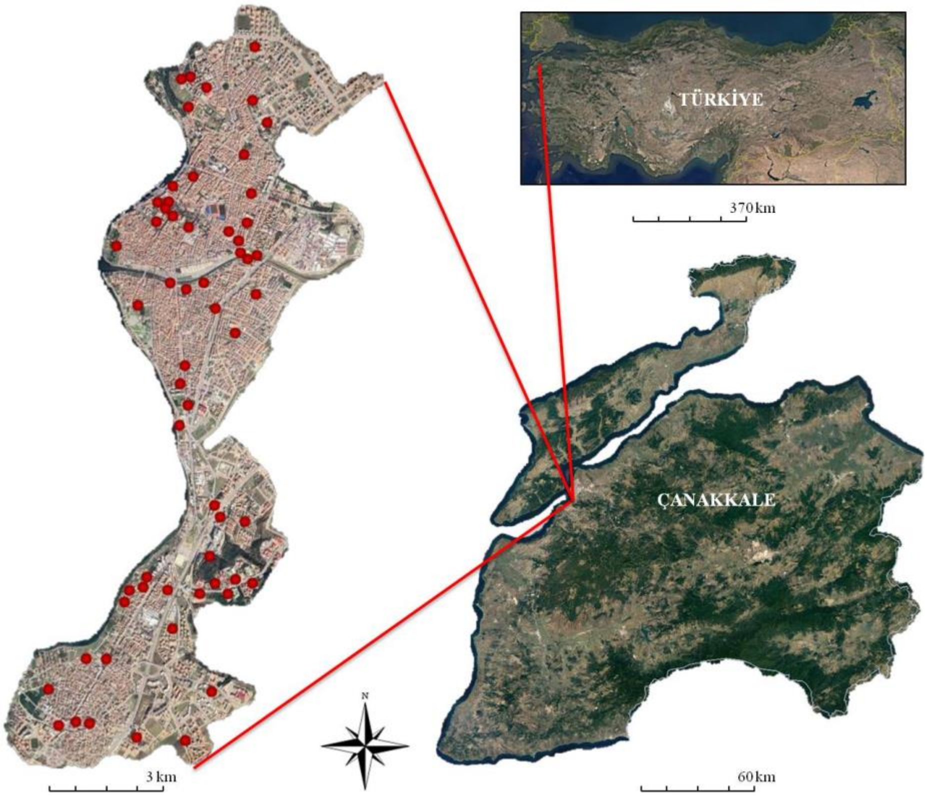

Figure 1. Map showing our sampling area in the Çanakkale Province of northwest Türkiye.

The sampling method and identification of the aphids and their hosts

In order to determine the diversity and interactions of aphids on different plant communities in the urban ecosystem, aphid sampling was conducted from the host plants such as trees, shrubs and herbaceous plants in parks, landscaped areas, roadsides, and gardens of homes and buildings in the city centre of Çanakkale located in the northwest of Türkiye. For the homogeneous sampling, all the areas here were visited once a week or sometimes more between April and October from 2021 to 2022. To determine the presence of aphid colonies, different parts of all the plant species were checked. The individuals of the aphid colonies on the host plants were put in cryotubes filled with 70% ethanol. Afterward, these specimens were clarified and prepared according to the protocol proposed by Hille Ris Lambers (1950). The identification of sampling specimens was carried out by the second author based on the keys of Blackman & Eastop (2006, 2023) using a LEICA DM 2500 microscope with LAS software and an HD camera. The scientific names of the identified aphids were provided and checked from Favret (2023). For the identification of host plants, trees or shrubs were photographed during the aphid sampling, and herbaceous plants were brought to the laboratory for the herbarium. The slide materials of the identified aphid species were kept in the Plant Protection Department of Agricultural Faculty in Çanakkale Onsekiz Mart University.

Data analysis

For visualization of the network of aphids-hosts interactions on different plant communities such as trees, shrubs and herbaceous plants in the urban ecosystem, the interaction graphs were constituted by using the "plotweb" function of the Bipartite software based on the relative abundance data of aphids and their hosts. For the calculation of the biodiversity values of the aphids-hosts interactions on different plant communities, i.e. Shannon's diversity index (*H'*), interaction evenness (*E*), *H2*, linkage density, links per species and connectance, were used for the "networklevel" function of the Bipartite software. Also, the modularity *(M)* and nestedness *(N)* values of the aphids-hosts interaction networks were calculated using the functions of "metaComputeModules" and "nested" (Beckett, 2016) in the Bipartite (Dormann et al., 2021). In addition, the "diversityresult" function in the BiodiversityR of R software (3.6.1) (Kindt & Kindt, 2019; R Core Team, 2023) was used to calculate the biodiversity values such as the richness *(S)* and abundance *(N)* of the aphids on the trees, shrubs and herbaceous plants.

Results and Discussion

The diversity of the aphids in the urban ecosystem

This study has revealed the diversity of the aphids and the interactions of aphid-host plants in different plant communities in a specific urban area, and determined 55 aphid species from 26 genera in the family Aphididae (Hemiptera) on 65 host plant species belonging to 26 plant families. Of these aphids, *Capitophorus archangelskii* (A23) and *Uroleucon leontodontis* (A54) are new to the aphid fauna of Türkiye. Also, *Brachycaudus tragopogonis setosus* (A21), *Cinara neubergi* (A29) and *Lipaphis lepidi* (A36), which are only reported in a few regions, are rare aphid species recorded in Türkiye. In addition to these species, *Aphis cytisorum* (A4), *Chaetosiphon tetrarhodum* (A24), *Chaitophorus populeti* (A26), *Rhopalosiphum nymphaeae* (A46) and *Uroleucon cichorii* (A52) were recorded for the first time in the Çanakkale Province, where this study was conducted. In terms of the genera diversity of the aphids, the most aphid species were identified in the genera *Aphis* with fifteen species, followed by the genera *Uroleucon* with five species. On the other hand, only one species from the genera *Brevicoryne*, *Capitophorus*, *Chaetosiphon*, *Eucallipterus*, *Hyperomyzus*, *Liosomaphis*, *Lipaphis*, *Macrosiphoniella*, *Myzus*, *Panaphis*, *Phorodon*, *Rhodobium*, *Sarucallis*, *Sitobion*, *Tinocallis* and *Trama* were identified. The aphid species identified in this study are presented in Table 1.

Table 1 The aphid species determined in the urban ecosystem

Code	Aphid Species	Code	Aphid Species	Code	Aphid Species
A1	*Acyrthosiphon gossypii* Mordvilko,1914	A20	*Brachycaudus* sp.	A39	*Macrosiphum rosae* (Linnaeus, 1758)
A2	*Acyrthosiphon lactucae* (Passerini, 1860)	A21	*Brachycaudus tragopogonis setosus* (Hille Ris Lambers, 1948)	A40	*Macrosiphum* sp.
A3	*Aphis craccivora* Koch, 1854	A22	*Brevicoryne brassicae* (Linnaeus, 1758)	A41	*Myzus persicae* (Sulzer, 1776)
A4	*Aphis cytisorum* Hartig, 1841	A23	*Capitophorus archangelskii* Nevsky, 1928	A42	*Panaphis juglandis* (Goeze, 1778)
A5	*Aphis fabae* Scopoli, 1763	A24	*Chaetosiphon tetrarhodum* (Walker, 1849)	A43	*Phorodon humuli* (Schrank, 1801)
A6	*Aphis gossypii* Glover, 1877	A25	*Chaitophorus leucomelas* Koch, 1854	A44	*Rhodobium porosum* (Sanderson, 1900)
A7	*Aphis hederae* Kaltenbach, 1843	A26	*Chaitophorus populeti* (Panzer, 1801)	A45	*Rhopalosiphum maidis* (Fitch, 1856)
A8	*Aphis nasturtii* Kaltenbach, 1843	A27	*Cinara cedri* Mimeur, 1936	A46	*Rhopalosiphum nymphaeae* (Linnaeus, 1761)
A9	*Aphis nerii* Boyer de Fonscolombe, 1841	A28	*Cinara fresai* Blanchard, 1939	A47	*Sarucallis kahawaluokalani* (Kirkaldy, 1907)
A10	*Aphis pomi* De Geer, 1773	A29	*Cinara neubergi* (Arnhart, 1930)	A48	*Sitobion avenae* (Fabricius, 1775)
A11	*Aphis punicae* Passerini, 1863	A30	*Cinara tujafilina* (Del Guercio, 1909)	A49	*Tinocallis saltans* (Nevsky, 1929)
A12	*Aphis ruborum* (Börner & Schilder, 1931)	A31	*Eucallipterus tiliae* (Linnaeus, 1758)	A50	*Trama caudata* Del Guercio, 1909
A13	*Aphis rumicis* Linnaeus, 1758	A32	*Hyalopterus amygdali* (Blanchard, 1840)	A51	*Uroleucon aeneum* (Hille Ris Lambers, 1939)
A14	*Aphis solanella* Theobald, 1914	A33	*Hyalopterus pruni* (Geoffroy, 1762)	A52	*Uroleucon cichorii* (Koch, 1855)
A15	*Aphis* sp.	A34	*Hyperomyzus lactucae* (Linnaeus, 1758)	A53	*Uroleucon jaceae* (Linnaeus, 1758)
A16	*Aphis spiraecola* Patch, 1914	A35	*Liosomaphis berberidis* (Kaltenbach, 1843)	A54	*Uroleucon leontodontis* (Hille Ris Lambers, 1939)
A17	*Aphis umbrella* (Börner, 1950)	A36	*Lipaphis lepidi* (Nevsky, 1929)	A55	*Uroleucon sonchi* (Linnaeus, 1767)
A18	*Brachycaudus cardui* (Linnaeus, 1758)	A37	*Macrosiphoniella sanborni* (Gillette, 1908)		
A19	*Brachycaudus helichrysi* (Kaltenbach, 1843)	A38	*Macrosiphum euphorbiae* (Thomas, 1878)		

Of the aphids new for Türkiye, *C. archangelskii* (A23), which feeds on the undersides of the leaves of *Elaeagnus* spp. (Elaeagnaceae), is distributed in Afghanistan, the Caucasus, India, Iran, Kazakhstan, Pakistan, and Uzbekistan. Another new species, *U. leontodontis* (A54), is distributed on *Leontodon* spp. in Europe (Blackman & Eastop 2023). In this study, *C. archangelskii* (A23) was identified from *Elaeagnus angustifolia* (Elaeagnaceae) and *U. leontodontis* (A54) from *Leontodon* sp. (Asteraceae).

Detailed descriptions and slides of the new aphid species for Türkiye are provided below:

***Capitophorus archangelskii* Nevsky, 1928**

Specimens examined. Türkiye: 4 apterous viviparous ♀, Çanakkale, 07.VI.2022, on *E. angustifolia*.

Color of body of living apterous viviparous female is light green, oval shaped, about 1.725 mm. Body parts are densely bearing long and thick capitate hairs: 5 on antenna segment I, 4 on antenna segment II, 8 on antenna segment III, 16 on dorsal each abdominal segment 1-4 (Figure 2a, e). Apterous viviparous female specimens on the slide; whole antenna is pale (Figure 2b), 1.548 mm length, and about 0.898 x body length. Processus terminalis of antenna segment VI 5.579 x base part of antenna segment VI (Figure 2d). Antenna segment III about two times shorter than segment VI, antenna segment IV and V are close in length. Length of antenna segments (I-VI) 0.098-0.060-0.305-0.245-0.230-0.608 mm. Maximum hair length on antenna segment III about 0.933 x basal diameter of same segment III (Figure 2c). Width of head about 0.372 mm, and pale. Rostrum is pale (Figure 2g), the length of ultimate rostral segment (RIV+V) 0.189 mm and has only two hairs, RIV+V 2.039 x hind tarsus segment II. Whole segments of legs are pale. Femur with long capitate hairs (Figure 2h), hind tarsus segments I and II are 0.023 mm and 0.092 mm (Figure 2ı). Siphinculi is 0. 625 mm, pale, cylindrical, not swollen, distinctly imbricated and not reticulated zone (Figure 2f). Siphinculi 4.092 x cauda, 0.362 x body length, 2.052 x length of antenna segment III. Cauda with an average of six hairs is pale, broadly and very shorter than siphinculi (Figure 2f). Lenght of cauda is 0.153 mm, about 0.813 x RIV+V, 0.504 x length of antenna segment III, 1.276 x width of cauda.

Figure 2. *Capitophorus archangelskii*: a) the body of an apterous viviparous female; b) whole antenna; c) hair on the antenna segment III; d) antenna segment VI (base + processus terminalis); e) capitate hairs on the dorsal abdominal segments; f) siphinculi and cauda; g) rostrum and ultimate rostral segment; h) capitate hairs on the femur; ı) hind tarsus segments I and II; j) the body of an alatae viviparous female, k,l) secondary rhinaria on the antennal segment III, IV, V.

Specimens examined. Türkiye: 1 alatae viviparous ♀, Çanakkale, 07.VI.2022, on *E. angustifolia*.

Color of body of living alatae viviparous female is light green. Alatae viviparous female specimens on the slide; body is 1.686 mm (Figure 2j). Antenna is dark, 1.396 mm length, and about 0.827 x body length. Processus terminalis of antenna segment VI 5.891 x base part of antenna segment VI. Antenna segment III longer than IV, and shorter than VI. Length of antenna segments (I-VI) 0.077-0.056-0.314-0.200-0.177-0.572 mm. Secondary rhinaria of antenna segments: 24 on segment III, 11 on segment IV, 3 on segment V (Figure 2k, l). Width of head about 0.304 mm, and dark. Length of ultimate rostral segment (RIV+V) 0.165 mm and has only two hairs, RIV+V 1.918 x hind tarsus segment II. Mesothorax is deep brown or dark. Abdomen has a largely square dark green patch in front of siphinculi. Siphinculi is 0.398 mm, cylindrical and not swollen. Siphinculi 3.790 x cauda, 0.236 x body length, 1.267 x length of antenna segment III. Cauda with an average of six hairs is bluntly pointed, 0.105 mm, about 0.636 x RIV+V, 0.334 x length of antenna segment III, 1.500 x width of cauda.

Uroleucon leontodontis **(Hille Ris Lambers, 1939)**

Specimens examined. Türkiye: 8 apterous viviparous ♀, Çanakkale, 26.V.2021 and 24.VI.2021 on *Leontodon* sp.

Color of body of living apterous viviparous female is dark brown-shiny, and body length is 3.068 mm. Apterous viviparous female specimens on the slide; whole antenna is dark (Figure 3c) and about 1.328 x body length (Figure 3a, b), processus terminalis of antenna segment VI 5.868 x base part of the same segment (Figure 3e), length of antenna segments (I-VI) 0.193-0.119-1.265-0.685-0.591-1.269 mm. Antenna segment III has average 46 secondary rhinaria (Figure 3d), maximum hair length on antenna segment III about 0.756 x basal diameter of the ame segment. Width of head about 0.619 mm, and dark. Antennal tubercle well developed (Figure 3a). Rostrum is dark, the length of ultimate rostral segment (RIV+V) 0.250 mm and has 7-9 hairs (Figure 3ı), RIV+V 1.384 x hind tarsus segment II. Dorsal abdomen has distinctive dark markings mostly with hairs (Figure 3b, f). Segments of legs; coxa dark, trochanter and basal part of femur pale, apical part of femur and whole tibia dark. Segments I and II of hind tarsus are 0.046 and 0.180 mm, and dark (Figure 3g). First tarsal segment of legs has 5-5-5 hair number (Figure 3j). Siphinculi is 0.991 mm, wholly dark and with reticulated zone (Figure 3b, h). Siphinculi 1.507 x cauda, 0.321 x body length, 0.779 x length of antenna segment III. Cauda with an average of 16 hairs is tongue-shaped, and paler than siphinculi (Figure 3b, h). Lenght of cauda is 0.656 mm, about 2.614 x RIV+V, 0.518 x length of antenna segment III, 2.701 x width of cauda.

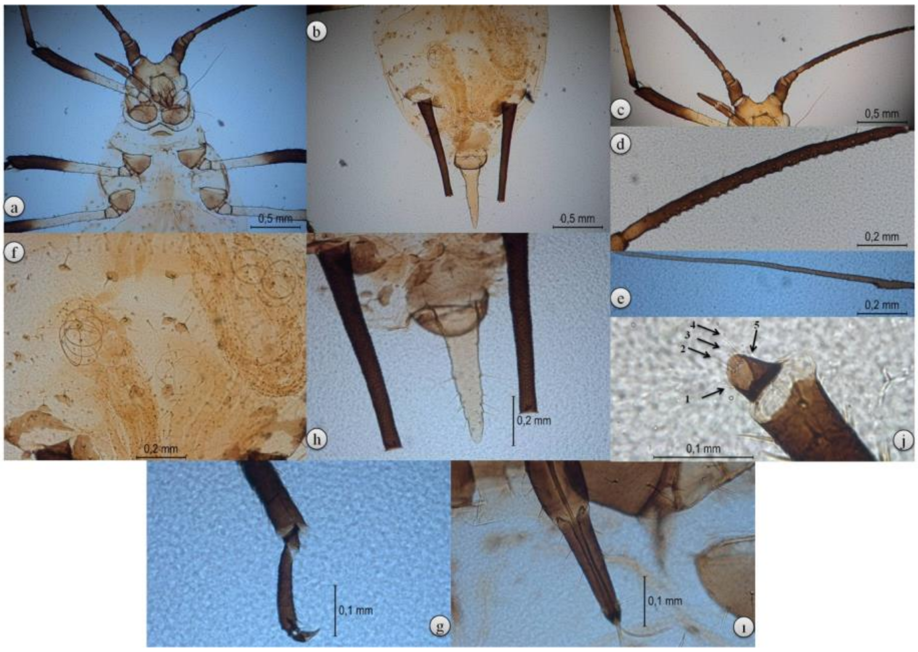

Figure 3. *Uroleucon leontodontis*: a,b) the body of an apterous viviparous female; c)whole antenna; d) secondary rhinaria on the antennal segment III; e) antennal segment VI (processus terminalis and the basal part of the antennal segment VI); f) dark markings on the abdomen; g) hind tarsus segments; h) siphinculi and cauda; ı) ultimate rostral segment; j) first tarsal segment.

The interactions of the aphids and host plants in the urban ecosystem

A total of 108 aphid-host plant interactions, including new interaction records were revealed in the urban ecosystem in the northwest Türkiye. From the different plant communities in the urban ecosystem, the highest aphid-host plant interactions were determined on the herbaceous plants with 52 interactions, followed by the trees with 32 interactions and the shrubs with 24 interactions. Among these, the interactions of *Aphis cytisorum* (A4) - *Spartium junceum* (Leguminosae) (H54), *Aphis spiraecola* (A16) - *Cercis siliquastrum* (Leguminosae) (H9) and *Kerria japonica* (Rosaceae) (H19), *Aphis solanella* (A14) - *Mirabilis jalapa* (Nyctaginaceae) (H29), *C. archangelskii*

(A23) - *E. angustifolia* (H13), *C. neubergi* (A29) - *Pinus pinea* (Pinaceae) (H34), and *U. leontodontis* (A54) - *Leontodon* sp. (H22) were recorded for the first time in Türkiye. The host plant species of the aphids identified in this study are presented in Table 2.

Table 2 The host plant species of the aphids determined in the urban ecosystem

Code	Host Plant	Code	Host Plant	Code	Host Plant
H1	Asteraceae	H23	*Lepidium draba* L. (Brassicaceae)	H45	*Robinia pseudoacacia* L. (Leguminosae)
H2	*Berberis thunbergii* DC. (Berberidaceae)	H24	*Malus floribunda* Siebold ex Van Houtte (Rosaceae)	H46	*Rosa* sp. (Rosaceae)
H3	*Brassica* sp. (Brassicaceae)	H25	*Malva sylvestris* L. (Malvaceae)	H47	*Rubus* sp. (Rosaceae)
H4	*Capsella rubella* Reut. (Brassicaceae)	H26	*Malva vulgaris* Fr. (Malvaceae)	H48	*Rumex conglomeratus* Murray (Polygonaceae)
H5	*Capsicum annuum* L. (Solanaceae)	H27	*Medicago sativa* L. (Leguminosae)	H49	*Rumex crispus* L. (Polygonaceae)
H6	*Carduus pycnocephalus* L. (Asteraceae)	H28	*Medicago* sp. (Leguminosae)	H50	*Rumex patientia* L. (Polygonaceae)
H7	*Cedrus deodora* (Roxb. ex D.Don) G.Don (Pinaceae)	H29	*Mirabilis jalapa* L. (Nyctaginaceae)	H51	*Rumex* sp. (Polygonaceae)
H8	*Centaurea* sp. (Asteraceae)	H30	*Nerium oleander* L. (Apocynaceae)	H52	*Silybum marianum* (L.) Gaertn. (Asteraceae)
H9	*Cercis siliquastrum* L. (Leguminosae)	H31	*Oenothera biennis* L. (Onagraceae)	H53	*Sonchus* sp. (Asteraceae)
H10	*Chrysanthemum* sp. (Asteraceae)	H32	*Photinia serrulata* Siebold & Zucc. (Rosaceae)	H54	*Spartium junceum* L. (Leguminosae)
H11	*Citrus* sp. (Rutaceae)	H33	*Phragmites australis* (Cav.) Trin. ex Steud. (Poaceae)	H55	*Spiraea × vanhouttei* (Briot) Zabel (Rosaceae)
H12	*Dasypyrum villosum* (L.) Borbás (Poaceae)	H34	*Pinus pinea* L. (Pinaceae)	H56	*Tanacetum* sp. (Asteraceae)
H13	*Elaeagnus angustifolia* L. (Elaeagnaceae)	H35	*Pittosporum tobira* (Thunb.) W.T. Aiton (Pittosporaceae)	H57	*Tilia cordata* Mill. (Malvaceae)
H14	*Euonymus japonicas* Thunb. (Celastraceae)	H36	*Platycladus orientalis* (L.) Franco (Cupressaceae)	H58	*Tragopogon porrifolius* L. (Asteraceae)
H15	*Hedera helix* L. (Araliaceae)	H37	*Populus alba* L. (Salicaceae)	H59	*Tribulus terrestris* L. (Zygophyllaceae)
H16	*Hibiscus syriacus* L. (Malvaceae)	H38	*Portulaca oleracea* L. (Portulacaceae)	H60	*Ulmus minor* Mill. (Ulmaceae)
H17	*Juglans regia* L. (Juglandaceae)	H39	*Prunus cerasifera* Ehrh. (Rosaceae)	H61	*Viburnum tinus* L. (Adoxaceae)
H18	*Juniperus Sabina* L. (Cupressaceae)	H40	*Prunus domestica* L. (Rosaceae)	H62	*Vicia faba* L. (Leguminosae)
H19	*Kerria japonica* (L.) DC. (Rosaceae)	H41	*Prunus persica* (L.) Batsch (Rosaceae)	H63	*Vicia villosa* Roth (Leguminosae)
H20	*Lactuca viminea* (L.) J. Presl & C. Presl (Asteraceae)	H42	*Prunus* sp. (Rosaceae)	H64	*Wisteria sinensis* (Sims) Sweet (Leguminosae)
H21	*Lagerstroemia indica* L. (Lythraceae)	H43	*Punica granatum* L. (Lythraceae)	H65	*Zea mays* L. (Poaceae)
H22	*Leontodon* sp. (Asteraceae)	H44	*Pyracantha coccinea* M. Roem. (Rosaceae)		

Considering the aphid-host interactions on trees in the urban ecosystem, *Hyalopterus pruni* (A33) fed on four tree species and was the most common aphid. Also, *Aphis craccivora* (A3), *A. spiraecola* (A16) and *Hyalopterus amygdali* (A32) preferred three tree species for feeding. On the other hand, the remaining aphids were mostly determined on only one tree species. As for the host trees, *Prunus domestica* (Rosaceae) (H40) and *Prunus* sp. (Rosaceae) (H42) visited by four aphid species were the most preferred host trees. These were followed by *Citrus* sp. (Rutaceae) (H11) and *Prunus persica* (Rosaceae) (H41), each preferred by three aphid species (Figure 4). When taking results for the shrubs into consideration, it becomes clear that diversity of the aphids, host plants and their interactions are significantly less than in the other plant communities. *Aphis spiraecola* (A16), collected from eight host shrubs species, was the most common aphid, and it was followed by *Aphis gossypii* (A6), collected from five host shrubs. As for the host shrubs, *Rosa* sp. (Rosaceae) (H46) was the most visited shrub species preferred by five aphids (Figure 5). Among all the plant communities, greatest diversity of aphids, host plants and their interactions were found for the herbaceous plants. In terms of aphids, *A. craccivora* (A3) and *Aphis fabae* (A5) fed on eight host herbaceous plants and were the most common. In this interaction network, each of the 19 aphid species was determined on only one host herbaceous plant. As for the host herbaceous plants, *Sonchus* sp. (Asteraceae) (H53) hosted the most aphids with five species (Figure 6).

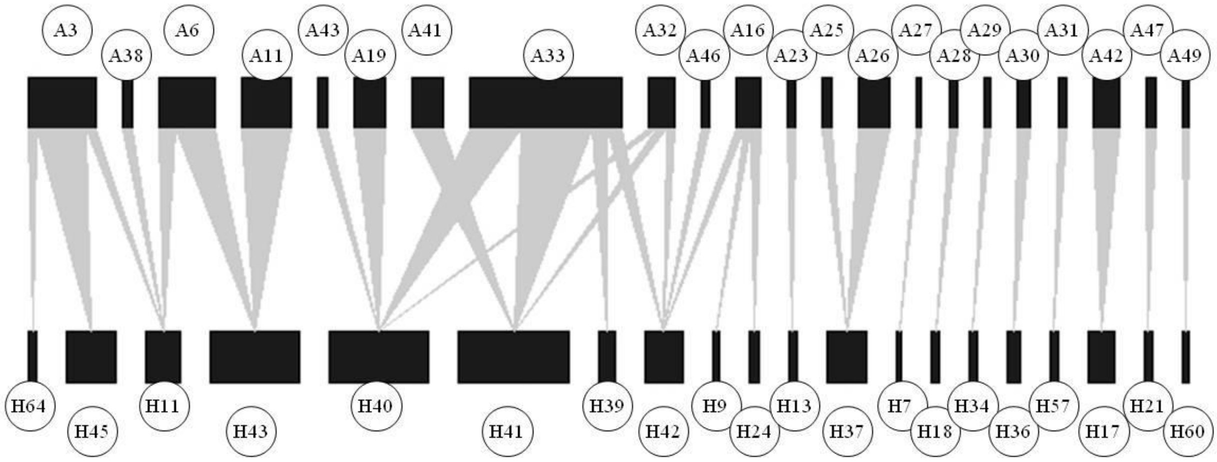

Figure 4. The graph showing the network of the aphids (upper part) - host trees (lower part) interactions in the urban ecosystem. The black bars and the grey bars show the abundance and interactions of the species, respectively.

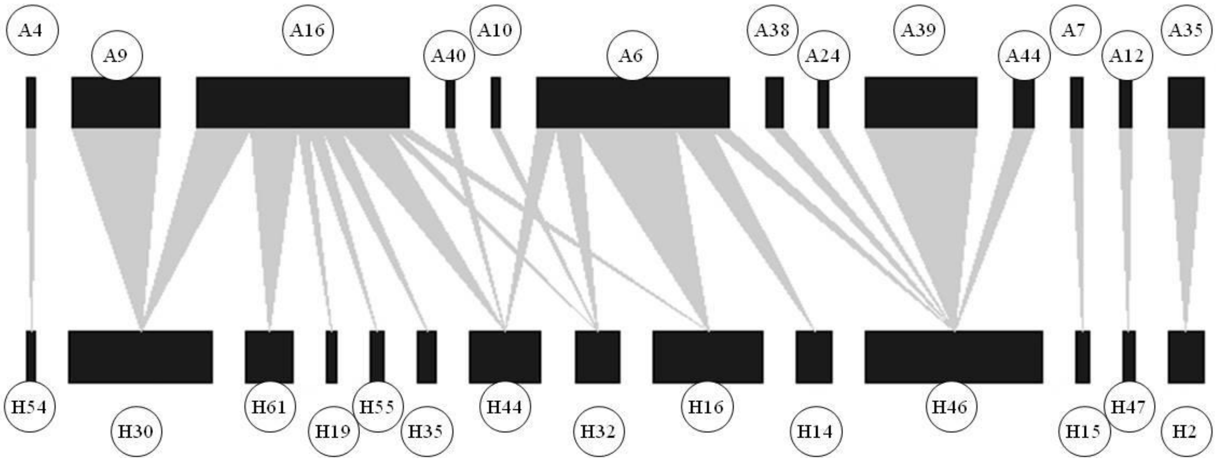

Figure 5. The graph showing the network of the aphids (upper part) - host shrubs (lower part) interactions in the urban ecosystem. The black bars and the grey bars show the abundance and interactions of the species, respectively.

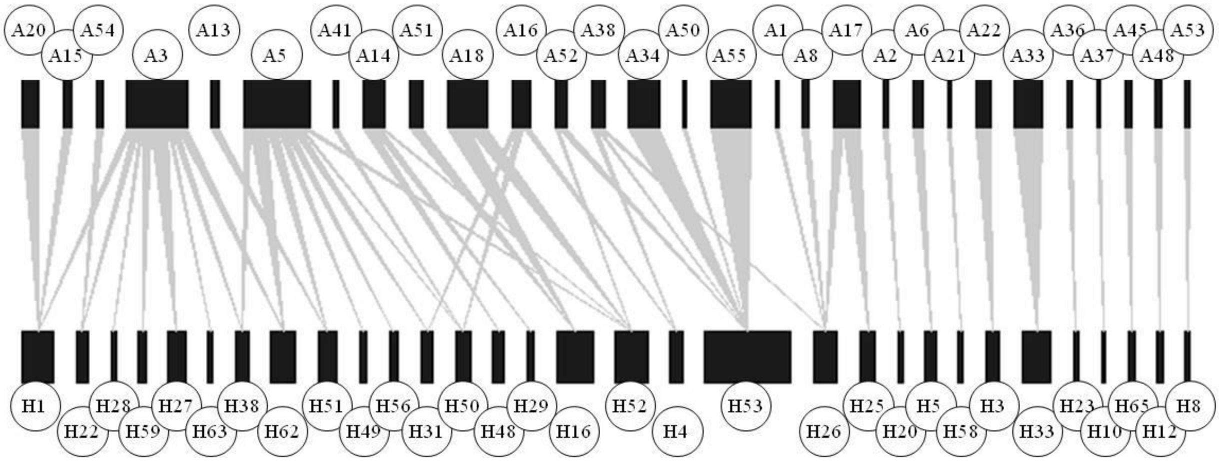

Figure 6. The graph showing the network of the aphids (upper part) - host herbaceous (lower part) interactions in the urban ecosystem. The black bars and the grey bars show the abundance and interactions of the species, respectively.

In our study of the species richness of aphids in different plant communities in an urban ecosystem, the results showed that the aphids on the host herbaceous plants have higher species richness than those on the host trees and shrubs (*S*= 29 on HH, *S*=22 on HT, *S*= 13 on HS). Similarly, the abundance of aphids on the host herbaceous plants was also higher than in the other plant communities (*N*= 2170 on HH, *N*=1502 on HT, *N*= 1674 on HS) (Table 3). To reveal more detailed information on the aphid-host plant interactions on the different plant communities in the urban ecosystem, we also obtained data on the biodiversity of these interactions. The connectance value, i.e. the realised proportion of possible links, was higher in the host shrubs than the other plant communities. Similarly, while the highest value of links per species was recorded for the host shrubs, the lowest value was found for the host trees. Also, the results of the analysis of the nestedness and modularity values of the interactions in different plant communities clearly showed that the network of interactions in the host trees was more nested than those on the host shrubs and herbaceous (*N*= 17.412 on HT, *N*= 13.712 on HS, *N*= 8.492 on HH). But, the network of interactions on the host herbaceous was more modular than those on the host trees and shrubs (*M*= 0.777 on HH, *M*= 0.717 on HT, *M*= 0.628 on HS). The biodiversity of the aphid-host plant interactions on the different plant communities in the urban ecosystem clearly showed that the interactions on the host herbaceous plants were more diverse than those on the host trees and shrubs (*H'*= 3.720 on the HH, *H'*= 3.150 on the HT, *H'*= 2.821 on the HS). Concordantly, the interaction evenness value for the host herbaceous plants was more balanced compared to the other plant communities (*E*= 0.547 on HH, *E*= 0.542 on HS, *E*= 0.517 on HT). The values of H2, which is defined as a network-level measure of specialisation, revealed that the specialisation in the network of aphid-host trees and aphid-host herbaceous plants was higher than in that of aphid-host shrubs (Table 3). The results thus clearly showed that in the urban ecosystem, diversity of the network of aphid-host herbaceous plants was higher than that in the host trees and shrubs.

Table 3 The biodiversity values of aphids and their host interactions on different plant communities in the urban ecosystem

Networks	Biodiversity of aphids		Biodiversity of interactions of aphids - different plant communities							
	Richness *(S)*	Abundance *(N)*	Connectance	Links per species	Linkage density	Nestedness *(N)*	Modularity *(M)*	Shannon diversity of interactions *(H')*	Interaction evenness *(E)*	H2
Network of aphids - host trees (HT)	22	1502	0.073	0.762	2.023	17.412	0.717	3.150	0.517	0.859
Network of aphids - host shrubs (HS)	13	1674	0.131	0.889	2.683	13.712	0.628	2.821	0.542	0.717
Network of aphids - host herbaceous plants (HH)	29	2170	0.057	0.866	2.557	8.472	0.777	3.720	0.547	0.841

Discussion

Urban areas are home to many ecosystems such as parks, landscaped areas, roadsides, and the gardens of homes and buildings with different plant communities. Furthermore, urbanisation can support biodiversity thanks to rich habitat diversity, providing new shelter and food sources for many invertebrates (Weller & Ganzhorn, 2004; Breuste et al., 2008; Bennewicz & Barczak, 2014). Urban ecosystems are known to affect populations of aphids in certain plant communities (Jaśkiewicz, 2005). In addition, aphids, which are one of the important groups of sucking insects, can provide an important food source for parasitoids, predators and other animals in both crop and non-crop habitats. Therefore, any increase or decrease in aphid populations can affect the presence and numbers of these organisms in urban ecosystems (Kamiński et al., 2016; Tena et al., 2016). In this regard, detailed data on the presence, species richness, relative abundance, host plant communities' preferences and biodiversity of aphids in urban ecosystems will contribute to a better understanding of the aphid-host plant interactions in these areas.

In their study on aphids in urban ecosystems, Bennewicz & Barczak (2016) investigated the diversity of aphids in two different plant communities, i.e. the so-called southern slope and downtown in the city of Bydgoszcz in Poland. As a result, they revealed a total of 39 aphid species with 32 aphids on 31 hosts in the southern neighbourhood and 24 aphid species on 23 hosts in the other area. Six aphid species were also determined on the genera of *Prunus*, i.e. *Prunus cerasifera* (Rosaceae) and *P. domestica*, in the sampling area. Similar results were obtained in our study, where seven aphid species, namely *A. spiraecola*, *Brachycaudus helichrysi*, *H. pruni*, *Myzus persicae*, *Phorodon humuli* and *R. nymphaeae* were identified on host trees belonging to the genera

Prunus. Hence, it may be interpreted that some plants from host trees in the genera *Prunus* are very attractive to aphids in both urban and crop ecosystems since urban ecosystems comprise not only ornamental plants in parks and landscaped areas, but also crop trees such as cherry, peach and plum in areas including roadsides and the gardens of homes and buildings. In another study, Borowiak-Sobkowiak & Wilkaniec (2010) identified 67 aphids on 56 host shrubs and host trees in the Park of Cytadela in the city of Poznan in Poland, which included one of the host plant ecosystems we focused on in our study. In our study, 32 aphid species were determined on 34 trees and shrubs in areas containing all urban ecosystems. However, it should be noted that in addition to aphid species on the trees and shrubs in urban ecosystems, our study also focused on the host herbaceous plants in these areas. From this perspective, the result of the determination of 29 aphid species on 31 host herbaceous plants in our study showed that aphid diversity is quite high on herbaceous plants as well as trees and shrubs in urban areas. Also, Borowiak-Sobkowiak & Wilkaniec (2010) emphasised that certain aphid species reduced the decorative value of ornamental plants by causing damage such as the discoloration, leaf curling, and drying of plant parts. In parallel with this, our study yielded some similar observations, although our data is not quantitative. Our observations showed that *Aphis nerii* and *A. spiraecola*, *A. craccivora*, *Liosomaphis berberidis* and *Macrosiphum rosae* caused serious decorative damage to the stems, leaves and flowers of *Nerium oleander* (Apocynaceae), *Robinia pseudoacacia* (Leguminosae), *Berberis thunbergii* (Berberidaceae) and *Rosa* sp., respectively. In another study, which investigated plant communities and associated aphid communities in different urban park ecosystems, 66 aphid species were identified on 75 plant species (Barczak et al., 2021). The results of the study emphasised that the differences between the aphid assemblages were closely related to the plant diversity in urban park plantations. The results from our study, revealing 52 aphid-host interactions on herbaceous plants, 32 aphid-host interactions on trees and 24 aphid-host interactions on shrubs, strongly support these data.

The studies presented above as well as the results of our study clearly demonstrate that urban ecosystems harbour rich aphid biodiversity and aphid-host plant interactions. Although many studies have been carried out on aphid interactions on all host plant communities in urban areas, the lack of data on the biodiversity of aphid-host plant interactions on different plant communities such as trees, shrubs, and herbaceous plants separately was considered an important gap. Considering that some aphid species have a heteroecious life cycle (Blackman & Eastop, 2023), it is clear that discovering more about these pests and their interactions on different plant communities is necessary in order to gain a better understanding of the biology and control strategies of aphids. In this regard, our results supporting this phenomenon showed that *A. gossypii* and *Macrosiphum euphorbiae*, which are important polyphagous aphid species, were determined on all three plant communities, as well as *A. craccivora*, *H. pruni*, and *M. persicae* on both the host trees and herbaceous plants in the urban ecosystem in in the northwest of Türkiye. Furthermore, the fact that the aphid species mentioned here are important ornamental plant pests in landscaped areas supports the need for a more detailed investigation of aphid - host plant interactions on different plant communities in urban ecosystems. Such a detailed investigation of aphid diversity and their host plant interactions in urban ecosystems will contribute not only to determining the control strategies of pest aphids after their infestation of plants, but also to the selection of trees and shrubs with high resistance to aphid damage thus enhancing the pest control programmes of ornamental plants. Additionally, different host plant communities in urban ecosystems can host the interactions of aphids' natural enemies, especially parasitoids. Numerous studies on this subject have shown that some host plants such as *B. thunbergii*, *Euonymus* sp. (Celastraceae), *Hibiscus syriacus* (Malvaceae), *N. oleander*, *Rosa* sp., *Salix alba* (Salicaceae), *Tamarix chinensis* (Tamaricaceae), and *Viburnum* sp. (Adoxaceae) are reservoirs for numerous parasitoid-aphid interactions (Lumbierres et al., 2005; Tomanović et al., 2006, 2009; Kavallieratos et al., 2013, 2016). These reserve hosts can contribute significantly to the biocontrol of aphid pests in urban areas where the use of chemicals is undesirable due to the density of human populations.

For the reasons presented here, it may be concluded that investigation of aphid-host interactions in different plant communities in urban ecosystems will contribute to closing an important gap. The results we present in this study show that urban ecosystems host a very rich aphid diversity, and these areas have significant potential to reveal new aphid species and aphid-host interaction records for cities and countries. Since not only certain landscape and ornamental plants, but also many herbaceous or cultivated plants such as tree species are commonly distributed in urban ecosystems, it is believed that the results of the host plant preference of aphids among the different plant communities in the urban ecosystems in our study have the potential to serve as an important guide in the design of landscape plants, pest control management and biological control of pest aphids in these areas.

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