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Biodiversity of the natural enemies of aphids (Hemiptera: Aphididae) in Northwest Turkey

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Abstract In the present study, the natural enemies of aphids (Hemiptera: Aphididae) and their host plants including herbaceous plants, shrubs and trees were analysed to reveal their biodiversity and disclose tritrophic associations in different habitats of the South Marmara region of northwest Turkey. As a result of field surveys, 58 natural enemy species associated with 43 aphids on 58 different host plants were identified in the region between March of 2017 and November of 2018. In 173 tritrophic natural enemy-aphid-host plant interactions including association records new for Europe and Turkey, there were 21 representatives of the family Coccinellidae (Coleoptera), 14 of the family Syrphidae (Diptera) and 15 of the subfamily Aphidiinae (Hymenoptera), as well as eight other generalist natural enemies. In these interactions, a total of 37 aphid-natural enemy associations–including 19 associations of *Acyrthosiphon pisum* (Harris) with natural enemies, 16 associations of *Therioaphis trifolii* (Monell) with natural enemies and two associations of *Aphis craccivora* Koch with natural enemies–were detected on *Medicago sativa* L. during the sampling period. Similarly, 12 associations of *Myzus cerasi* (Fabricius) with natural enemies were revealed on *Prunus avium* (L.), along with five associations of *Brevicoryne brassicae* (Linnaeus) with natural enemies (including mostly parasitoid individuals) on *Brassica oleracea* L. Also in the study, reduviids of the species *Zelus renardii* (Kolenati) are reported for the first time as new potential aphid biocontrol agents in Turkey. The results of field surveys show that the natural enemies of aphids have high biodiversity, which should be considered in the management of biological pest control.

Keywords Biological control · Aphididae · Coccinellidae · Syrphinae · Aphidiinae · South Marmara

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Introduction

As one of the most important of agricultural pests, aphids (Hemiptera, Aphididae) cause severe significant economic losses and are distributed in most terrestrial ecosystems throughout the world. They damage agricultural crops, forest plants and shade trees, especially in temperate regions, as a result of sap-sucking, honeydew

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secretion and transmission of phytopathogenic viruses (Alford 2011; Diehl et al. 2013).

Natural enemies, including specialist and generalist species, play a very important role in suppressing populations of aphids and other arthropod herbivores (Symondson et al. 2002; Lu et al. 2012), Such natural enemies affect at least 50% of all aphid species on the surface of the earth (Waage 1991). Up to now, about 2000 arthropods, generally consisting of parasitoid species, have been determined as biological control agents worldwide (van Lenteren et al. 2006). Aphids are usually attacked by natural enemies such as parasitoids, predators and some pathogens. Of these, both the larvae and the adult stages of coccinellid species are predaceous on aphids, while only the larval stages of syrphids and chrysopids are predaceous on them. Also among parasitoids, species belonging to the family Braconidae (especially members of the subfamily Aphidiinae) develop as solitary endoparasitoids on aphid populations (Völkl et al. 2007).

Surveying the biodiversity of natural enemies of herbivore pests in both agricultural and natural habitats is quite important from the standpoint of planning biological control strategies. A richness of natural enemies makes possible stronger biological control in all habitats (Letourneau et al. 2009; Griffin et al. 2013; Katano et al. 2015). When the taxonomic distance between natural enemies on herbivore pests was high, the effect of this phenomenon was likewise positive (Griffin et al. 2013). However, greater diversity of natural enemies can lead to more ineffective pest control in agricultural habitats (Snyder and Wise 2001; Montoya et al. 2003).

In addition, the nature of associations of aphid and their host plants in different habitats can regulate the efficacy of influence exerted by specialist and generalist natural enemies on aphid populations. According to the hypothesis of host physiological phenotype, host plants that are nutrient-rich and short-lived tend to increase the density of aphids (Cronin et al. 2010), as in the case of populations of other nitrogen-limited herbivores (Mattson 1980), because host plants with a great amount of nitrogen have a positive effect on the development of aphid populations (Schütz et al. 2008). In view of the aforementioned considerations, the biodiversity of natural enemies and their interactions with both pests and host plants were here investigated in detail so as to better understand enemy-herbivore-host plant associations.

The aim of the present study was to reveal biodiversity of the natural enemies of pest aphids in different habitats of the South Marmara region of northwest Turkey, which is an important crossroad between Europe and Asia and has a rich and diverse flora and fauna.

Material and methods

Sampling area

Our sampling area, the South Marmara region in northwest Turkey, consists of the Çanakkale and Balıkesir Provinces, which constitute an important link between Europe and Asia. This area includes 3% of Turkey's land, with a surface area of 783.562 km^2, and it is an outstanding region in terms of agricultural production. The region has a continental climate in the southeastern parts, milder climate in parts close to the coastal area and Mediterranean climate in regions of the gulf and islands. The sampling area also includes wilderness areas such as the Edremit Gulf, Biga Peninsula, Gallipoli Peninsula and Kaz Dağları (Ida Mountains), which are known to have a high degree of endemic floristic and faunistic diversity (Özhatay and Özhatay 2005).

Collection and identification of aphids and their natural enemies

Specimens of aphids and their natural enemies were collected from their host plants, including herbaceous plants, shrubs and trees in different habitats such as cultivated (simple landscapes-1), uncultivated (complex landscapes-2) and urban areas (3) in the Çanakkale and Balıkesir Provinces in northwest Turkey between March of 2017 and November of 2018. Accordingly, all samples were marked in the catalogue of associations. Sufficient numbers of apterous and alate specimens of aphids were transferred with a soft brush to Eppendorf tubes containing 70% ethyl alcohol for identification. The aphid specimens were identified by the first author using a LEICA DM 2500 microscope with a mounted HD camera and LAS software (version 4.1) according to Blackman and Eastop (2006, 2018) and Kök et al. (2016); Kök and Kasap (2019). Adults of natural enemies, especially ladybirds, hoverflies and generalist predators such as representatives of Hemiptera, Dermaptera and Neuroptera, were collected from host plants infested with aphids by visual and hand searching using sweep nets and suction tubes, after which they were brought to the laboratory in plastic

boxes and glass jars for preparation and identification. For sampling of predator larvae and parasitoids, different parts of aphid-infested plants including predator larvae and mummified aphids were brought in the same boxes to the laboratory for emergence of adult specimens. The larvae of predators were kept until they were adults in the aphid-containing plastic boxes, the upper part of which was covered with a net. For parasitoid emergence, mummified individuals in aphid colonies on the host plants were put in plastic bottles and kept in laboratory conditions (22.5 °C, 65% humidity, 16:8 L:D photoperiod). After the emergence of adult predators and parasitoids, the specimens of natural enemies of aphids were sent to competent experts for identification. Specimens belonging to the subfamily Aphidiinae (Braconidae) and families Syrphidae and Coccinellidae were identified by the second, third and fourth authors, respectively. Permanent slides of identified aphids and ladybird specimens were deposited in the library of slides maintained by the Department of Plant Protection, Faculty of Agriculture, Çanakkale Onsekiz Mart University. Specimens of other natural enemies were deposited in personal collections of the identifying experts.

Results and discussion

In determining biodiversity of the natural enemies of aphids in the present study, 58 natural enemy species associated with 43 aphids on 58 different host plants were recorded in different habitats of the South Marmara region of northwest Turkey during surveys conducted from 2017 to 2018. These enemies included 21 species of ladybird beetles of the family Coccinellidae (Coleoptera), whose members are one of the most frequently encountered natural enemies in all regions of Turkey. To be specific, Aslan and Uygun (2005) reported 33 coccinellid species feeding on 59 aphids in Kahramanmaraş and emphasized that the most common enemy is *Coccinella septempunctata* Linnaeus, which was found feeding on 41 aphid species. Also, Kök et al. (2017) determined that *C. septempunctata* is the most collected predator, with a 35,1% availability rate for aphids in Çanakkale, including our current survey area. These results are corroborated by the data we obtained in the present study, in which associations between *C. septempunctata* and 12 aphids were found in the South Marmara region. Species of the family Syrphidae, widely recognized as aphidophagous hoverflies, are one of the most common known natural enemies of aphid populations (Chambers 1988) and are important agents for the biological control of many pests under both agricultural and greenhouse conditions (Pineda and García 2008; Leroy et al. 2010; Amorós-Jiménez et al. 2012). The most effective of them, larvae of the species *Episyrphus balteatus* de Geer, feed on about 100 aphid species throughout the world (Sadeghi and Gilbert 2000). In the same vein, Bayrak and Hayat (2008) stated that *E. balteatus* preys on 33 aphid species and is common in many regions of Turkey. Similarly, we found that the larvae of this hoverfly species feed on 10 aphid species harmful to many cultivated plants and are commonly encountered in our study area.

Among the most notable details in the catalogue of tritrophic relationships given below are the aphid-natural enemy associations on *Medicago sativa* L. Alfalfa (*M. sativa*) is the most widely used fodder crop worldwide (Walton 1983) and some aphid species such as *Acyrthosiphon pisum* (Harris); *Acyrthosiphon kondoi* Shinji; *Therioaphis trifolii* and *Aphis craccivora* have been reported as major pests of alfalfa fields in different parts of the world (Summers 1976; Nakashima and Akashi 2005; Rakhshani et al. 2006). These fields can also serve as rich reservoir areas for the natural enemies of aphids (Summers 1998) and researching the associations between aphids and their natural enemies in alfalfa fields is important to improve biological control strategies. As a result of sampling from different alfalfa fields, we detected a total of 37 associations of aphids with natural enemies, including 19 associations of *A. pisum* with natural enemies, 16 associations of *T. trifolii* with natural enemies and two associations of *A. craccivora* with natural enemies on *M. sativa* during the sampling period, as indicated in the catalogue below. Similarly, 12 associations of *M. cerasi* with natural enemies on *Prunus avium* (L.) were revealed in this study, along with five associations of *B. brassicae* with natural enemies (including mostly parasitoid individuals) on *Brassica oleracea* L.

The surprising finding of *Zelus renardii* (Kolenati), a generalist predator of leafhoppers, is one of the most interesting results of the present study. This generalist is a species native to North and Central America, from which it then began to spread to Hawaii and other tropical areas of the Pacific region (Weirauch et al. 2012). The predator later reached Greece and the Balkan Peninsula, which are close neighbours of Turkey (Davranoglou 2011; Simov et al. 2017). The first

finding of Z. renardii in the Turkish fauna was recorded by Çerçi and Koçak (2016) from İstanbul and İzmir, close to the European continent and the Balkan Peninsula. In another study, *Z. renardii* was determined as a natural enemy of *Glycaspis brimblecombei* (Moore) feeding on *Eucalyptus camaldulensis* Dehnh (Yurt and Karaca 2018). Finally, *Z. renardii* associated with *Cinara tujafilina* (Del Guarcio) feeding on *Platycladus orientalis* is here determined for the first time as a predator of aphids in Turkey (in the South Marmara region). We feel that as a natural enemy, this generalist predator has the potential to be an agent for the biological control of aphids, and that records of its finding will be reported from different habitats and regions of Turkey in years to come. However, it should not be forgotten that *Z. renardii* is an intraguild predator of the larvae of *Chrysoperla carnea* (Stephens), an important agent for the biological control agent of aphids (Rosenheim et al. 1993; Cisneros and Rosenheim 1997).

On the other hand, parasitoid species, generally taxa belonging to the subfamily Aphidiinae (Hymenoptera: Braconidae), are specialist natural enemies of aphid populations and attack by laying their eggs in the body of nymphs and adult instars of their prey aphids (Bai and Mackauer 1990; Ralec 1995). Up to now, a number of authors have conducted various studies to determine the species of aphid parasitoids in many regions of Turkey, and they have contributed new records for the Turkish fauna (Ölmez and Ulusoy 2003; Aslan et al. 2004; Çetin Erdoğan et al. 2008; Tomanović et al. 2008; Kök et al. 2017). In the present study, we identified 15 parasitoid species from the subfamily Aphidiinae (Hymenoptera: Braconidae) associated with 26 aphids feeding on 30 host plant species. Also in this study, we collected as aphid natural enemies one species belonging to Chamaemyiida (Diptera) and two species of hyperparasitoids that cannot be identified. However, they were not included in the evaulation of tritrophic associations.

The interactions between aphids and their host plants are an important phenomenon affected by the nature of the habitat of host plants and aphids, location of the habitat and acceptance of aphids as prey by their natural enemies. The odours emitted by aphid-uninfested plants are a powerful guide enabling natural enemies to easily find their prey aphid on host plants in different habitats (Hatano et al. 2008). For example, allyl isothiocyanate and methyl salicylate emitted by the host plants *Brassica* oleraceae and *Glycine max* attract *Diaeretiella rapae*, *C. septempunctata* and syrphid flies, which are the primary natural enemies of *B. brassicae* and *Aphis glycines* (Read et al. 1970; Zhu and Park 2005). Also, chemical and physical cues such as the alarm pheromone honeydew, its smell, aphid body colour and the shape and movement of aphids are effective factors enabling suitable prey aphids to be reached by both their parasitoids and their predators (Michaud and Mackauer 1994; Harmon et al. 1998). In light of the foregoing considerations, we have catalogued below the natural enemy-prey aphid-host plant associations in the South Marmara region of northwest Turkey so that these interactions in different habitats can be better understood and used more effectively in strategies for the biological control of aphids. In the present study, 173 tritrophic natural enemy-aphid-host plant associations (including association records new for Europe and Turkey) were determined that consisted of 58 natural enemies, 43 aphids and 58 different host plant species, as shownin the catolague below.

Catalogue of plant-aphid-predator/parasitoid associations from the South Marmara region of northwest Turkey.

Amaranthus albus L. (Amaranthaceae)

Aphis craccivora Koch, 1854: *COCCINELLIDAE (Coleoptera): *Hippodamia variegata* Goeze, 1777 (1). *SYRPHIDAE (Diptera): *Paragus tibialis* (Fallén, 1817) (1). ***Note:** The association between *A. craccivora* and *P. tibialis* is recorded for the first time on host plants such as *A. albus*.

Amaranthus retroflexus L. (Amaranthaceae)

Aphis craccivora: *SYRPHIDAE (Diptera): *P. tibialis* (1). ***Note:** The association between *A. craccivora* and *P. tibialis* is recorded for the first timeon host plants such as *A. retroflexus*.

Apiaceae (unidentified plant species)

Unidentified aphid species 1: *SYRPHIDAE (Diptera): *Episyrphus balteatus* (de Geer, 1776) (1).

Asteraceae (unidentified plant species)

Unidentified aphid species 2: *SYRPHIDAE (Diptera): *Eupeodes corollae* (Fabricius, 1794) (3); *Eupeodes*

luniger (Meigen, 1822) (2); *Meliscaeva auricollis* (Meigen, 1822) (3); *Scaeva pyrastri* (Linnaeus, 1758) (3).

Uroleucon sp.: *BRACONIDAE (Hymenoptera): *Aphidius funebris* Mackauer, 1961 (2); *Praon yomenae* Takada, 1968 (2).

Berberis sp. (Berberidaceae)

Liosomaphis berberidis (Kaltenbach, 1843): *COCCINELLIDAE (Coleoptera): *Coccinella septempunctata* Linnaeus, 1758 (3).

Berberis thunbergii DC. (Berberidaceae)

L. berberidis: *COCCINELLIDAE (Coleoptera): *C. septempunctata* (3); *Harmonia axyridis* Pallas, 1773 (3); *H. variegata* (3).

Brassica oleracea L. (Brassicaceae)

Brevicoryne brassicae (Linnaeus, 1758): *COCCINELLIDAE (Coleoptera): *C. septempunctata* (1). *SYRPHIDAE (Diptera): *E. corollae* (1); *S. pyrastri* (1); *Scaeva selenitica* (Meigen, 1822) (1). ***Note:** The association between *S. selenitica* and *B. brassicae* is recorded for the first time in Turkey. This relationship was previously documented only from Poland (Malinowska 1973; Rojo et al. 2003). *BRACONIDAE (Hymenoptera): *Diaeretiella rapae* (Curtis, 1860) (1).

Capsella rubella Reut. (Brassicaceae)

Aphis craccivora: *BRACONIDAE (Hymenoptera): *Lysiphlebus fabarum* (Marshall, 1896) (2); *Lysiphlebus testaceipes* (Cresson, 1880) (2).

Carlina sp. (Asteraceae)

Uroleucon jaceae (Linnaeus, 1758): *BRACONIDAE (Hymenoptera): *P. yomenae* (2).

Catalpa bignonioides Walter (Bignoniaceae)

Aphis catalpa Mamontova, 1953: *COCCINELLIDAE (Coleoptera): *Adalia bipunctata* (Linnaeus, 1758) (3).

Chenopodium album L. (Amaranthaceae)

Aphis fabae Scopoli, 1763: *BRACONIDAE (Hymenoptera): *Binodoxys angelicae* (Haliday, 1833) (1).

Aphis solanella Theobald, 1914: *COCCINELLIDAE (Coleoptera): *H. variegata* (2).

Hayhurstia atriplicis (Linnaeus, 1761): *SYRPHIDAE (Diptera): *E. balteatus* (1). *BRACONIDAE (Hymenoptera): *B. angelicae* (2); *D. rapae* (2).

Chrysanthemum sp. (Asteraceae)

Aphis gossypii Glover, 1877: *BRACONIDAE (Hymenoptera): *Aphidius colemani* Viereck, 1912 (3).

Crepis sp. (Asteraceae)

A. gossypii: *BRACONIDAE (Hymenoptera): *Aphidius matricariae* Haliday, 1834 (2).

Cupressus arizonica Greene (Cupressaceae)

Cinara fresai Blanchard, 1939: *COCCINELLIDAE (Coleoptera): *Adalia decempunctata* (Linnaeus, 1758) (3); *C. septempunctata* (3); *Nephus includens* (Kirsch, 1870) (3).

Cydonia oblonga mill. (Rosaceae)

Ovatus insitus (Walker, 1849): *COCCINELLIDAE (Coleoptera): *A. bipunctata* (1); *C. septempunctata* (1).

Cynara scolymus L. (Asteraceae)

Brachycaudus cardui (Linnaeus, 1758): *SYRPHIDAE (Diptera): *E. balteatus* (1).

Cynara sp. (Asteraceae)

B. cardui: *COCCINELLIDAE (Coleoptera): *C. septempunctata* (2). *SYRPHIDAE (Diptera): *S. selenitica* (2). ***Note:** This is a new aphid-syrphid association according to Rojo et al. 2003.

Cynoglossum creticum mill. (Boraginaceae)

Acyrthosiphon malvae (Mosley, 1841): *COCCINELLIDAE (Coleoptera): *C. septempunctata* (1); *Scymnus pallipediformis* Gunther, 1958 (1).

Euphorbia rigida M.Bieb. (Euphorbiaceae)

Aphis vallei Hille Ris Lambers & Stroyan, 1959: *COCCINELLIDAE (Coleoptera): *Scymnus apetzi* Mulsant, 1846 (2). *SYRPHIDAE (Diptera): *Scaeva albomaculata* (Macquart, 1842) (2). ***Note:** This is a new aphid-syrphid association. Additionally, this syrphid species is found for the first time on a host plant from the genus *Euphorbia* (Rojo et al. 2003). *BRACONIDAE (Hymenoptera): *Ephedrus persicae* Froggatt, 1904 (2).

Hedera helix L. (Araliaceae)

Aphis hederae Kaltenbach, 1843: *BRACONIDAE (Hymenoptera): *B. angelicae* (3).

Hibiscus syriacus L. (Malvaceae)

A. gossypii: *BRACONIDAE (Hymenoptera): *L. testaceipes* (3).

Juniperus oxycedrus L. (Cupressaceae)

Cynara oxycedri Binazzi, 1996: *BRACONIDAE (Hymenoptera): *Pauesia* sp. Quilis, 1931 (3).

Lactuca sp. (Asteraceae)

Acyrthosiphon lactucae (Passerini, 1860): *BRACONIDAE (Hymenoptera): *A. matricariae* (2).

Malus domestica Borkh. (Rosaceae)

Dysaphis plantaginea (Passerini, 1860): *COCCINELLIDAE (Coleoptera): *A. bipunctata* (1); *N. includens* (1). *CHRYSOPIDAE (Neuroptera): *Chrysoperla carnea* (Stephens, 1836) (1). *BRACONIDAE (Hymenoptera): *A. matricariae* (1); *E. persicae* (1).

A. gossypii: *BRACONIDAE (Hymenoptera): *B. angelicae* (1); L. testaceipes (1).

Malus floribunda Siebold ex Van Houtte (Rosaceae)

Aphis pomi De Geer, 1773: *BRACONIDAE (Hymenoptera): *Lipolexis gracilis* Forster, 1862 (3); *Lysiphlebus cardui* (Marshall, 1896) (3); *L. fabarum* (3).

Malva sp. (Malvaceae)

Aphis umbrella (Börner, 1950): *BRACONIDAE (Hymenoptera): *A. matricariae* (2).

Malva sylvestris L. (Malvaceae)

A. umbrella: *BRACONIDAE (Hymenoptera): *Lysiphlebus confusus* Tremblay & Eady, 1978 (1).

Matricaria sp. (Asteraceae)

Unidentified aphid species 2: *BRACONIDAE (Hymenoptera): *L. testaceipes* (2).

Medicago sativa L. (Leguminosae)

Acyrthosiphon pisum (Harris, 1776): *COCCINELLIDAE (Coleoptera) (1): *A. decempunctata*; *C. septempunctata*; *Coccinula quatuordecimpustulata* (Linnaeus, 1758); *Exochomus nigromaculatus* Goeze, 1777; *Hippodamia tredecimpunctata* Linnaeus, 1758; *H. variegata*; *Propylea quatuordecimpunctata* (Linnaeus, 1758); *Psyllobora vigintiduopunctata* (Linnaeus, 1758); *S. apetzi*; *S. pallipediformis*; *Scymnus quadriguttatus* Fürsch et Kreissl, 1967. *SYRPHIDAE (Diptera) (1): *E. balteatus*; *E. corollae*; *Melanostoma mellinum* (Linnaeus, 1758); *S. pyrastri*; *Sphaerophoria* scripta (Linnaeus, 1758). *CHRYSOPIDAE (Neuroptera) (1): *C. carnea*. *BRACONIDAE (Hymenoptera) (1): *Aphidius ervi* Haliday, 1834; *Aphidius banksae* Kittel, 2016.

Aphis craccivora: *COCCINELLIDAE (Coleoptera): *S. apetzi* (1). *SYRPHIDAE (Diptera): S. pyrastri (1).

Therioaphis trifolii (Monell, 1882): *COCCINELLIDAE (Coleoptera) (1): *A. bipunctata*; *C. quatuordecimpustulata*; *E. nigromaculatus*; *H. variegata*; *P. quatuordecimpunctata*; *P. vigintiduopunctata*; *S. apetzi*; *S. pallipediformis*; *Scymnus rubromaculatus* (Goeze, 1778). *SYRPHIDAE (Diptera) (1): *E. corollae*; S. scripta; *Sphaerophoria rueppellii* Wiedemann, 1830. ***Note:** The association between *S. rueppellii* and *T. trifolii* is the first record in

Turkey. Before the present study, this association was confirmed only in Poland in Europe (Rojo et al. 2003). Also, the *E. corollae*-T. trifolii and S. scripta-*T. trifolii* associations are recorded for the first time in Turkey, having been previosly known only from Poland in the whole Europe (Bankowska et al. 1975; Rojo et al. 2003). *MIRIDAE (Hemiptera) (1): *Deraeocoris serenus* (Douglas & Scott, 1868). *NABIDAE (Hemiptera): *Nabis pseudoferus* Remane, 1949. *CHRYSOPIDAE (Neuroptera) (1): *C. carnea*. *HEMEROBIIDAE (Neuroptera) (1).

Nerium oleander L. (Apocynaceae)

Aphis nerii Boyer de Fonscolombe, 1841: *COCCINELLIDAE (Coleoptera): *A. bipunctata* (3); *A. decempunctata* (3); *P. quatuordecimpunctata* (3). *BRACONIDAE (Hymenoptera): *A. colemani* (3); *B. angelicae* (3); L. testaceipes (3).

Aphis spiraecola Patch, 1914: *COCCINELLIDAE (Coleoptera): *A. decempunctata* (3); *P. quatuordecimpunctata* (3).

Philadelphus coronarius L. (Hydrangeaceae)

Aphis fabae mordvilkoi Börner & Janich, 1922: *BRACONIDAE (Hymenoptera): *L. testaceipes* (3).

Pistacia terebinthus L. (Anacardiaceae)

Baizongia pistaciae (Linnaeus, 1767): *FORFICULIDAE (Dermaptera): *Forficula smyrnensis* Audinet-Serville, 1839 (1).

Platycladus orientalis (L.) Franco (Cupressaceae)

Cinara tujafilina (Del Guercio, 1909): *COCCINELLIDAE (Coleoptera): *A. decempunctata* (3); *C. septempunctata* (3); *H. axyridis* (3); *Harmonia quadripunctata* (Pontoppidan, 1763) (3); *Oenopia conglobata* (Linnaeus, 1758) (3); *S. pallipediformis* (3); *Scymnus subvillosus* (Goeze, 1777) (3). *ANTHOCORIDAE (Hemiptera): *Zelus renardii* (Kolenati, 1856) (3).

Portulaca oleracea L. (Portulacaceae)

Aphis craccivora: *SYRPHIDAE (Diptera): *P. tibialis* (1). ***Note:** The association between *A. craccivora* and *P. tibialis* is recorded for the first time on host plants such as *P. oleracea*. *BRACONIDAE (Hymenoptera): *L. testaceipes* (1).

Prunus avium (L.) L. (Rosaceae)

Myzus cerasi (Fabricius, 1775): *COCCINELLIDAE (Coleoptera) (1): *A. bipunctata*; *Adalia fasciatopunctata revelieri* Mulsant, 1866; *A. decempunctata*; *Chilocorus bipustulatus* (Linnaeus, 1758); *H. axyridis*; *O. conglobata*. *SYRPHIDAE (Diptera) (1): *E. balteatus*; *Paragus pecchiolii* Rondani, 1857. ***Note:** The association of M. cerasi and *E. balteatus* is recorded for the first time in Turkey. Also, the association between *M. cerasi* and *P. pecchiolii* is recorded for the first time in Europe. *FORFICULIDAE (Dermaptera) (1): *Forficula aetolica* Brunner, 1882; *Forficula auricularia* Linnaeus, 1758; *F. smyrnensis*. *BRACONIDAE (Hymenoptera): *A. matricariae* (1).

Prunus domestica L. (Rosaceae)

Brachycaudus helichrysi (Kaltenbach, 1843): *COCCINELLIDAE (Coleoptera): *P. quatuordecimpunctata* (1). *SYRPHIDAE (Diptera): *E. balteatus* (1). *BRACONIDAE (Hymenoptera): *E. persicae* (1).

Hyalopterus pruni (Geoffroy, 1762): *COCCINELLIDAE (Coleoptera): *A. bipunctata* (1). *SYRPHIDAE (Diptera): *E. balteatus* (1).

Prunus dulcis (mill.) D.a.Webb (Rosaceae)

Hyalopterus amygdali (Blanchard, 1840): *COCCINELLIDAE (Coleoptera): *A. bipunctata* (3).

Prunus persica (L.) Batsch (Rosaceae)

Brachycaudus amygdalinus (Schouteden, 1905): *COCCINELLIDAE (Coleoptera): *C. septempunctata* (1).

Punica granatum L. (Lythraceae)

Aphis punicae Passerini, 1863: *COCCINELLIDAE (Coleoptera): *A. f. revelieri* (1). *BRACONIDAE (Hymenoptera): *A. matricariae* (1); *B. angelicae* (1); *L. testaceipes* (1).

Pyracantha coccinea M.Roem. (Rosaceae)

A. spiraecola: *COCCINELLIDAE (Coleoptera): *A. bipunctata* (3); *H. axyridis* (3). *SYRPHIDAE (Diptera): *E. balteatus* (3). ***Note:** This is an aphid-syrphid association new in Turkey.

Rosa sp. (Rosaceae)

Macrosiphum euphorbiae (Thomas, 1878): *COCCINELLIDAE (Coleoptera): C. septempunctata (2).

Macrosiphum rosae (Linnaeus, 1758): *COCCINELLIDAE (Coleoptera): *C. septempunctata* (3). *SYRPHIDAE (Diptera): *E. balteatus* (2); S. pyrastri (3). ***Note:** The association of *M. rosae* and *E. balteatus* is recorded for the first time in Turkey.

Rumex crispus L. (Polygonaceae)

Aphis rumicis Linnaeus, 1758: *COCCINELLIDAE (Coleoptera): *Platynaspis luteorubra* (Goeze, 1777) (2).

Rumex pulcher L. (Polygonaceae)

A. rumicis: *BRACONIDAE (Hymenoptera): *B. angelicae* (1); *L. fabarum* (1).

Rumex sp. (Polygonaceae)

A. solanella: *BRACONIDAE (Hymenoptera): *B. angelicae* (2); *L. fabarum* (2).

Sambucus nigra L. (Adoxaceae)

Aphis sambuci Linnaeus, 1578: *COCCINELLIDAE (Coleoptera): A. bipunctata (3); *O. conglobata* (3).

Scabiosa sp. (Caprifoliaceae)

M. rosae: *COCCINELLIDAE (Coleoptera): *S. apetzi* (2).

Silybum marianum (L.) Gaertn. (Asteraceae)

A. fabae: *BRACONIDAE (Hymenoptera): *L. testaceipes* (2).

Solanum americanum Mill. (Solanaceae)

A. solanella: *SYRPHIDAE (Diptera): S. pyrastri (1).

Sonchus sp. (Asteraceae)

Hyperomyzus lactucae (Linnaeus, 1758): *SYRPHIDAE (Diptera): *E. balteatus* (1); *Paragus quadrifasciatus* Meigen, 1822 (1). ***Note:** The association between *H. lactucae* and *P. quadrifasciatus* is recorded for the first time in Turkey. This association was previously documented only in Spain (Marcos García 1981, 1985; Rojo et al. 2003) and Portugal (Rojo et al. 2003).

Spiraea vanhouttei (Briot) Zabel (Rosaceae)

A. spiraecola: *COCCINELLIDAE (Coleoptera): *A. bipunctata* (3). *SYRPHIDAE (Diptera): *E. balteatus* (3). ***Note:** This is an aphid-syrphid association new in Turkey.

Tamarix sp. (Tamaricaceae)

Brachyunguis tamaricis (Lichtenstein, 1886): *COCCINELLIDAE (Coleoptera): *A. decempunctata* (3); *H. variegata* (3); *O. conglobata* (3).

Tribulus terrestris L. (Zygophyllaceae)

Aphis craccivora: *SYRPHIDAE (Diptera): *Paragus haemorrhous* Meigen, 1822 (2). ***Note:** This is an aphid-syrphid relationship new in Turkey. The association was previously recorded only in Spain (Rojo and Marcos García 1998; Rojo et al. 2003) and Portugal (Gomes 1981; Rojo et al. 2003).

Triticum aestivum L. (Poaceae)

Sitobion avenae (Fabricius, 1775): *COCCINELLIDAE (Coleoptera): *C. quatuordecimpustulata* (1).

Urtica urens L. (Urticaceae)

A. solanella: *SYRPHIDAE (Diptera): *S. selenitica* (2). ***Note:** This is a new aphid-syrphid association according to Rojo et al. 2003.

Veronica sp. (Plantaginaceae)

A. gossypii: *COCCINELLIDAE (Coleoptera): *C. septempunctata* (2). *BRACONIDAE (Hymenoptera): *B. angelicae* (2).

Viburnum opulus L. (Adoxaceae)

A. spiraecola: *BRACONIDAE (Hymenoptera): *L. fabarum* (3); *L. testaceipes* (3).

Viburnum tinus L. (Adoxaceae)

A. spiraecola: *COCCINELLIDAE (Coleoptera): *A. bipunctata* (3).

Vicia faba L. (Leguminosae)

Aphis craccivora: *BRACONIDAE (Hymenoptera): *L. gracilis* (1).

In conlusion, results of the present study reveal natural enemy-aphid-host plant associations and disclose biodiversity of the natural enemies of aphids in the South Marmara region of northwest Turkey, which is known for having a richly diversified fauna and flora. Fifty-eight natural enemies, 43 aphid species and 58 host plants were identified in the study, and 173 tritrophic associations of them were determined in all habitats. The vast majority of identified aphids and species of their natural enemies are new records for the fauna of the South Marmara region. We feel that determining biodiversity of the natural enemies of aphids–including harmful species that cause economically significant losses of crops–contributes both to more effective planning of strategies for biological control of these pests and to creation of an inventory of the region's faunal biodiversity. It is generally known that a high biodiversity of natural enemies strengthens the possibilities of achieving biological control. However, it should not be forgotten that the richness or absence of natural enemy biodiversity can have either a positive or a negative impact on the biological control of pests (Jonsson et al. 2017). Accordingly, it is believed that research in the future should be focused on the mechanisms governing interactions between natural enemies, pests and their host plants in order to increase the chances for success of biological pest control.

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