

Notes on distribution, host associations, and bionomics of *Erythmelus klopomor* Triapitsyn (Hymenoptera, Mymaridae), an egg parasitoid of lace bugs in Missouri, USA, with particular reference to its primary host *Corythucha arcuata* (Say) (Hemiptera, Tingidae)

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Abstract

The fairyfly *Erythmelus klopomor* Triapitsyn (Hymenoptera, Mymaridae) is an idiobiont, multivoltine egg parasitoid of lace bugs (Hemiptera, Tingidae). The parasitoid apparently reproduces thelytokously and at present is only known in the USA from 36 counties in Missouri, two in Illinois, four in Florida and one each in North Carolina and Maryland. At least a somewhat wider occurrence of the parasitoid is indicated because of the ease by which it has been reared from its primary host the oak lace bug, *Corythucha arcuata* (Say). It also has been reared in Missouri from the additional hosts *C. cydoniae* (Fitch), *C. marmorata* (Uhler), *C. pergandei* Heidemann, *C. ciliata* (Say), and also from *Gargaphia solani* Heidemann (a new host record). The parasitoid is short lived with an average life cycle of 14.5 days and

apparently overwinters as an adult. *Erythmelus klopomor* should be considered as a candidate classical biological control agent against the recently introduced *C. arcuata* in Bulgaria, northern Italy, Switzerland, and Turkey, and also possibly against the well-established invasive *C. ciliata* in Europe.

Introduction

Lace bugs (Hemiptera, Tingidae) are commonly found on a variety of ornamental shrubs, urban and forest trees, and weeds (Johnson & Lyon, 1991; Horn *et al.*, 1979) and at times may warrant control measures if only to enhance esthetics on their respective host plants. Natural enemies, primarily an array of predators (*e.g.* lacewings, *Orius* spp. minute pirate bugs, assassin bugs, and predacious mirid bugs), and unaccountable mortality of eggs are cited as factors contributing to reducing damage caused by lace bug species (Connell & Beacher, 1947; Horn *et al.*, 1983). Sheeley & Yonke (1977) studied seven species of lace bugs in Missouri, USA, and found no evidence of parasitoids attacking any life stages of them. An exception was the egg parasitoid *Anagrus takeyanus* Gordh (Hymenoptera, Mymaridae) which parasitizes the azalea, *Stephanitis pyrioides* (Scott), and andromeda, *S. takeyai* Drake & Maa, lace bugs in Connecticut, southeastern USA, and Japan (Balsdon *et al.*, 1996; Gordh & Dunbar, 1977; Tsukada, 1999). There are very few references on the species of egg parasitoids attacking lace bugs in the USA (Gordh, 1979; Huber, 1986). Huber (1986) and Triapitsyn (2003) reviewed the world literature on host associations of the egg parasitoids in the family Mymaridae and the genus *Erythmelus* Enock, respectively, and found the only references pertaining to their relationships with lace bugs were occasional species in the genera *Anagrus* Haliday or *Erythmelus*. These were recorded in all zoogeographical regions except the Nearctic where there are no other described species of *Anagrus* or *Erythmelus* associated with lace bugs with the exception of the previously mentioned *A. takeyanus* (Gordh & Dunbar, 1977) and *A. virginiae* Triapitsyn & Puttler (Puttler & Triapitsyn, 2006). Yet an *Erythmelus* sp. was mentioned as being reared in the USA from the sycamore lace bug, *Corythucha ciliata* (Say), the hawthorn lace bug, *C. cydoniae* (Fitch), and *C. floridana* Heidemann (Horn *et al.*, 1979; Horn *et al.*, 1983; Triapitsyn, 2003).

On 25 July 2003 a lace bug determined (by B. Puttler and corroborated by R.L. Blinn) to be oak lace bug (OLB), *Corythucha arcuata* (Say), was found infesting a bur oak (*Quercus macrocarpa* Michaux) (Fagaceae) on the University of Missouri – Columbia (Boone Co.). Eggs were readily observed on the underside of leaves and a serendipitous collection (ca. 10 egg clusters) was made from which 12 and 13 days

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later (6 and 7 August) mymarid parasitoids emerged. An additional collection of OLB eggs on 31 July 2003 also produced parasitoids as did a collection of OLB eggs from Howard Co. on 6 August 2003 which yielded parasitoids four days later. One of the authors (S.V. Triapitsyn) determined the parasitoid as probably a new, previously undescribed species of *Erythmelus*, which somewhat resembled the Neotropical tingid egg parasitoid *E. tingitiphagus* (Soares), and subsequently described it as *E. klopomor* Triapitsyn (Triapitsyn *et al.*, 2007). The Missouri specimens are identical to specimens of *E. klopomor* from Florida, North Carolina, and Maryland in the USA (Triapitsyn *et al.*, 2007). Later, Peña *et al.* (2009) reported *E. klopomor* also as an egg parasitoid of the avocado lace bug, *Pseudacysta perseae* (Heidemann), in Florida.

Recoveries of the *E. klopomor* in Missouri and Illinois then represented new host records and distributions approximately 2000-2500 km from its other previously known locations (Table 1). Since a dearth of mymarid species host associations exists, an investigation of the parasitoid status in Missouri and elsewhere was undertaken.

Materials and methods

The University of Missouri Campus at Columbia, Missouri (UMC) (Boone Co.) and its Horticulture and AgroForestry Research Center (HARC) at New Franklin in Howard Co., both in central Missouri, were the major study sites. The UMC site is typical of an urban environment with a landscape of trees, shrubs, flowering plants, and weeds scattered throughout the campus. The HARC site is rural, consisting of an experimental plantation of a variety of trees and shrubs in the midst of an area of open fields, orchards, and pastures. Both sites harboured lace bugs with eight species present, seven *Corythucha* spp. and one *Gargaphia* sp., on their respective host plants which are listed in Table 2. In addition, the eggplant lace bug, *Gargaphia solani* Heidemann, was collected from horsenettle, *Solanum carolinense* L. (Solanaceae), at Concordia, Lafayette Co., Missouri.

In 2004 observations for OLB eggs located within the city of Columbia and at the HARC site began as trees leafed out in May and terminated by late September, when viable eggs were no longer present on host plants. In addition, one time surveys were conducted from June-September to determine distribution of the parasitoid *E. klopomor* from egg surveys collected from oak species (Table 2) at selected locations from 51 Missouri counties and 4 adjoining counties in Illinois (Table 1). Eggs from other lace bug species also were collected to delineate the potential host range of the parasitoid occurring in the study areas.

Sampling was performed visually on the various host plants by searching leaves that showed typical lace bug feeding, *e.g.* discoloration and whitening of the upper leaf surface (Connell & Beacher, 1947). Depending on the observed severity of the lace bug infestation various numbers of leaves were collected from one to five plants at each collection site, placed in sealed plastic bags and returned to the laboratory where they were examined under the microscope to reliably distinguish between hatched and unhatched eggs. Two types of oviposition were characterized by lace bug species. The eggs of *C. arcuata* and *C. cydoniae* were laid in irregular clusters, readily visible, varying in numbers (ca. 10-100+) and slightly embedded in leaf tissue, whereas, the eggs of *C. ciliata* and *C. pergandei* Heidemann were deeply embedded in pubescent leaf tissue along the veins, midribs, and secondary vein junctions and laid singularly or in groups of <10 (Barber & Weiss, 1922).

Rearing of *E. klopomor* from samples collected at all locations and dates was accomplished by excising the leaf portion containing unhatched eggs and placing them on the surface of filter paper lined 100x150 mm Petri dishes. The egg masses were monitored daily for 21 days for egg parasitoid emergence with most adults removed daily. These observations provided a means of estimating the parasitoids' develop-

Table 1. Known distribution of the oak lace bug parasitoid *Erythmelus klopomor* from recoveries in Missouri and other states in the USA.

State/County	Locality
Missouri	
Adair	Kirksville
Audrain	Mexico
Barton	Lamar
Boone	Columbia
Callaway	Fulton
Cedar	Eldorado
Clark	Kahoka
Clay	Smithville
Cole	Jefferson City
Dade	Greenfield
Dallas	Buffalo
Franklin	Gray Summit
Gasconade	Rosebud
Gentry	Albany
Henry	Clinton
Howard	New Franklin
Jackson	Blue Springs
Jefferson	Eureka
Johnson	Kingsville
Knox	Edina
Lafayette	Concordia
Lawrence	Mt. Vernon
Lewis	Lewiston
Livingston	Burger
Marion	Palmyra
Monroe	Madison
Pettis	Sedalia
Polk	Humansville
Ralls	New London
Saline	Sweet Springs
St. Charles	Weldon Springs
St. Claire	Osceola
St. Louis	St. Louis
Vernon	Nevada
Warren	Warrenton
Worth	Grant City
Illinois	
Henderson	Gladstone
Hancock	Nauvoo
Florida	
Broward	Pompano Bay
Palm Beach	West Palm Beach
Monroe	Islamorada
Okeechobee	Fort Drum
Osceola	Canoe Creek
Maryland	
Prince George	Greenbelt
North Carolina	
Wake	Raleigh

mental time from field collected eggs to adult emergence. A subsample of 15 emerged adults were placed in shell vials with and without a diluted honey food source to determine adult longevity under the rearing conditions described. In addition, a small number of adults were retained in Petri dish samples and observed under the microscope for ovipositional behavior when exposed to unparasitised lace bug eggs. These eggs were further monitored to determine the parasitoid life cycle from time of oviposition to adult emergence. Sample dishes were held in the laboratory where rearing conditions for both eggs and emerged adults ranged from 20-24°C with 8-10 h. of daily light exposure during the week and total darkness on weekends at ca. 40-50% R.H.

Voucher specimens of *E. klopomor* from this study are deposited in the collections of the Entomology Research Museum, University of California at Riverside, California, USA (UCRC) and W.R. Enns Entomological Museum, University of Missouri, Columbia, Missouri, USA (UMRM) (Triapitsyn *et al.*, 2007), and those of its lace bug hosts in the UMRM.

Results

Lace bug and plant host associations of *Erythmelus klopomor*

At the HARC study site, *C. arcuata* eggs were first detected on bur oak on 10 May 2004. Egg samples collected on this date and monitored

for adult parasitoid emergence did not yield parasitoids. From the next sample on 18 May and weekly samples thereafter, *E. klopomor* adults emerged from egg collections from each sampling date. The first adult parasitoids appeared on 2 June and the last on 27 September; 15 and 6 days post collection, respectively. Observations on bur oak at UMC deviated slightly. *C. arcuata* eggs were first seen and sampled on 12 May with subsequent collections on 21 and 27 May. No *E. klopomor* was reared from these collections. They were reared from each egg collection at this site starting 2 June and weekly thereafter till 1 October. The first parasitoid adults emerged on 11 June and were again present in each sample with the last emergence on 6 October, 9 and 5 days post collection, respectively. In both localities, minimum/maximum emergence times ranged from 1-17 days as per other collection dates with all variations in between. In 2004 the last parasitoids to emerge from the UMC bur oak samples of 1 and 3 October was 14 October. There were no apparent differences in the phenology of the OLB as to when the eggs were first observed at the study sites (10 *versus* 12 May). Yet there was a difference in first generation parasitoid emergence as *E. klopomor* appeared 9 days later at UMC than at HARC (11 *versus* 2 June).

At both UMC and HARC *E. klopomor* was reared from miscellaneous collections of *C. arcuata* infesting other oak species (Table 2). All of these oaks are referred to as *white oak* and the OLB is apparently specific to these oak species. *Red oaks* [e.g. *Q. rubra* Michaux (northern red oak), *Q. palustris* Muenchhausen (pin oak)] adjacent to and in close proximity to OLB infestations were never infested. *E. klopomor* also was reared

Table 2. Host plants of lace bugs (Tingidae) and those species serving as hosts for *Erythmelus klopomor at the University of Missouri study sites.**

Host plants	HARC	Tingid Species
UMC		
Fagaceae		
<i>Quercus alba</i> L. (white oak)	<i>Q. alba</i>	<i>Corythucha arcuata</i> (Say)* (oak lace bug)
<i>Q. macrocarpa</i> Michaux (bur oak)	<i>Q. macrocarpa</i>	
<i>Q. bicolor</i> Willdenow (swamp white oak)	<i>Q. bicolor</i>	
<i>Q. robur</i> J.F. Ehrhart (English oak)	<i>Q. robur</i>	
<i>Q. muehlenbergii</i> Engelman (chinkapin oak)	<i>Q. muehlenbergii</i>	
	<i>Q. prinoides</i> Willdenow (dwarf chinkapin oak)	
<i>Q. acutissima</i> Carruher (sawtooth oak)	<i>Q. acutissima</i>	
	<i>Q. gambellii</i> Nuttall (hybrid oak)	
	<i>Q. asjese</i> Willdenow (hybrid oak)	
Rosaceae		
<i>Aronia arbutifolia</i> L. (Persoon) (red chokeberry)	<i>A. arbutifolia</i>	<i>C. cydoniae</i> (Fitch)* (hawthorn lace bug)
<i>Crataegus viridis</i> L. (winter king hawthorn)		
Juglandaceae		
	<i>Juglans nigra</i> L. (black walnut)	<i>C. juglandis</i> (Fitch) (walnut lace bug)
Asteraceae		
<i>Aster novae-angliae</i> L. (New England aster)		<i>C. marmorata</i> (Uhler)* (chrysanthemum lace bug)
<i>Solidago altissima</i> L. (goldenrod)		
Betulaceae		
<i>Betula nigra</i> L. (river birch)	<i>B. nigra</i>	<i>C. pergandei</i> Heidemann*
Plantaceae		
<i>Platanus occidentalis</i> L. (sycamore)	<i>P. occidentalis</i>	<i>C. ciliata</i> (Say)*
Ulmaceae		
<i>Ulmus americana</i> L. (American elm)	<i>U. americana</i>	<i>C. ulmi</i> Osborn & Drake (elm lace bug)
Tiliaceae		
<i>Tilia americana</i> L. (American linden/basswood)	<i>T. americana</i>	<i>Gargaphia tiliae</i> (Walsh) (linden lace bug)

*Denotes lace bug species serving as hosts for *Erythmelus klopomor*.

from *C. cydoniae* on *Aronia arbutifolia* L. (Rosaceae) at HARC, but not from *C. ulmi* Osborn & Drake, *C. ciliata*, *C. juglandis* (Fitch) nor from *Gargaphia tiliae* (Walsh) at this locality. In contrast, all lace bug species at UMC except *G. tiliae* were hosts of *E. klopomor* (Table 2).

E. klopomor were reared from one-time collections of *C. arcuata* eggs in each of 36 Missouri counties (Figure 1, Table 1). Parasitoids were not detected in another 10 counties due to the absence of eggs and another 5 counties in which eggs yielded no parasitoids (Figure 1). We did recover parasitoids in two of four Illinois counties (Hancock Co. and Henderson Co.) from OLB on bur oak and these represent new Illinois state records as do our other samples for Missouri. The known hosts of *E. klopomor* at the study sites in Missouri are listed in Table 2.

Biology of *Erythmelus klopomor*

Based on our laboratory observations, *E. klopomor* is a solitary idiobiont parasitoid of lace bug eggs. It was found that unmated females produced females; therefore, the species apparently reproduces thelytokously even though occasional males are recorded (Triapitsyn *et al.*, 2007). Newly emerged females do not undergo a preovipositional period and are capable of ovipositing on or shortly after emergence (proviogenic). The adults are readily attracted to egg clusters where the eggs are examined by antennal palpitation to determine their suitability for

oviposition. Oviposition is apparently deterred if eggs are too far along in development or previously parasitized. No host feeding was observed. Acceptable eggs were mounted and the ovipositional act occurred via the ovipositor penetrating the egg through the rim of its operculum. The entire ovipositional procedure was completed in 3-5 min. The life cycle from egg to adult ranged from 11-17 days ($n=20$; mean of 14.15 ± 0.4 S.E.) under our rearing conditions and was ca. half the time (26-36 days) it took *A. takeyanus* to develop under similar rearing conditions (Balsdon *et al.*, 1996). As per some other mymarid species, the parasitoid emerges by pushing out the operculum. It is short lived, with or without a food source. Longevity was usually <48 h and was similar to that of *A. takeyanus*.

Discussion and conclusions

Five *Corythucha* spp. in Missouri (Table 2) plus *G. solani* (a new host record; eggs of this host had been collected in the same state but outside of the study sites, and these were successfully parasitized by *E. klopomor* when exposed in the laboratory), as well as *C. floridana* (Triapitsyn *et al.*, 2007) and *P. perseae* (Peña *et al.*, 2009), both in Florida, are recorded as hosts of *E. klopomor*. Based on our observa-

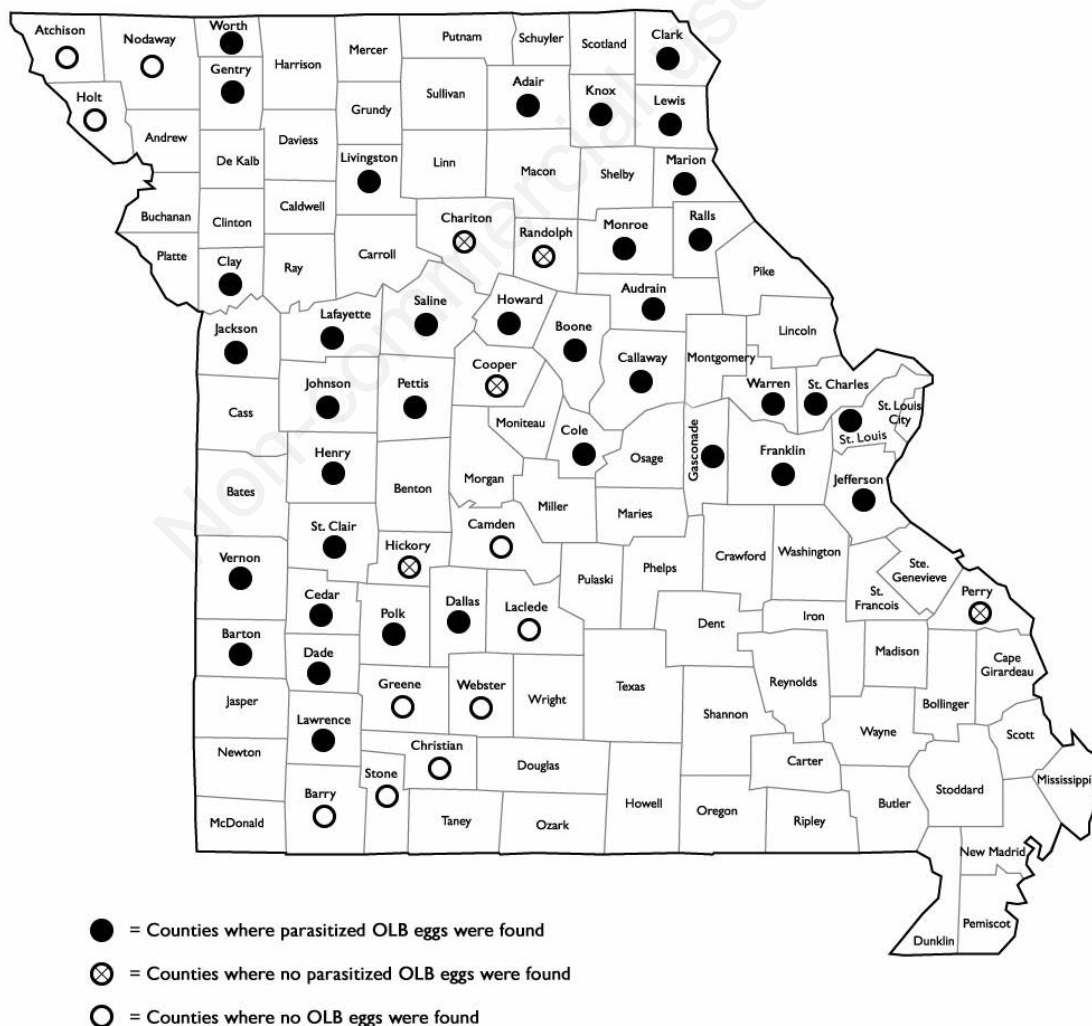


Figure 1. Distribution of *Erythmelus klopomor* in Missouri, USA.

tions the parasitoid was most readily reared from *C. arcuata* because this species oviposits eggs that are more easily accessible to *E. klopomor* females (larger numbers/cluster) and not as deeply embedded in leaf tissue. Next in preference was *C. cydoniae* with all other lace bugs serving as incidental hosts.

The ease in which they were recovered from samples of <10-30 viable egg clusters per county is indicative of at least a somewhat wider distribution of *E. klopomor* within Missouri and other states; however, the species is not yet known from the western USA. This assumption is based on the parasitoid's known distribution within Missouri (Figure 1), Illinois (a new state record), Florida, Maryland, and North Carolina from eggs of *C. ciliata* and *C. cydoniae* (Horn *et al.*, 1979; Horn *et al.*, 1983; Triapitsyn *et al.*, 2007). We predict that *E. klopomor* will eventually be found coincident with its primary hosts of *C. arcuata* and *C. cydoniae* since their distribution encompasses most of the USA as do their known insect hosts (Table 2) and related host plants (*i.e.* *Quercus* spp.).

Since all the known lace bug hosts of *E. klopomor* overwinter as adults (Barber & Weiss, 1922) the question arises as how this short lived parasitoid survives year-to-year, from ca. October until the following May when no host eggs were found. We are of the opinion that it overwinters as a diapausing adult in secluded niches on its hosts' host plants (cracks and crevices in trunk and branches) or in nearby environments. The latter unfortunately cannot be duplicated under artificial conditions. Puttler *et al.* (1973) came to a similar conclusion with another mymarid *Anaphes nigrellus* Girault [as *A. behmani* Girault (Huber, 1992)] as did Anderson & Paschke (1968) for *Anaphes flavipes* (Foerster). In contrast, *A. takeyanus* has a known overwintering stage (eggs) to maintain the species (Gordh & Dunbar, 1977; Tsukada, 1999).

Corythucha arcuata has recently become an invasive species in parts of Europe and also in the Asian part of Turkey (Mutun *et al.*, 2009). It was first detected in northern Italy in 2000 and subsequently found in Switzerland in 2002, Turkey in 2003, and the Balkan Peninsula (Bulgaria) in 2012 (Bernardinelli, 2000; Mutun, 2003; Forster *et al.*, 2005; Dobрева *et al.*, 2013). Should *C. arcuata* manifest itself as an oak pest in its present distribution and disperse throughout Europe as *C. ciliata* did on sycamore over the same area (Maceljski, 1986), *E. klopomor* could be useful as a candidate agent in a potential classical biological control program against this pest and also possibly against *C. ciliata* after an evaluation of the possibility that the parasitoid did not interfere with EU autochthonous lace bug species. The following considered parasitoid attributes could lend themselves to such a program: i) an apparently thelytokous reproduction; multivoltinism, short life cycle (at least half that of its preferred host); ii) preference for *C. arcuata*; iii) occurs in temperate, Mediterranean, and subtropical climates; and iv) parasitoid is readily collectable in its country of origin (USA).

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