SYSTEMATICS AND PHYLOGENY

Description and biological features of a new species of *Anagrus* Haliday (Hymenoptera, Mymaridae)

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Abstract

Anagrus lindberginae sp. n. (Hymenoptera: Mymaridae), an egg parasitoid of the leafhopper *Lindbergina aurovittata* (Homoptera: Cicadellidae), is described from Italy. It is included in the *atomus* group of *Anagrus* Haliday and compared with the allied known taxa. The parasitoid's life cycle is characterized by a long larval diapause from spring to fall, which allows for synchronization with its leafhopper host; other biological traits of *A. lindberginae* on the evergreen plant *Quercus ilex* are discussed.

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Contributions: FN contributed for the morpho-biological characterization of the new species; GV is the author of some taxonomic aspects of the paper and of the morphometric analysis of the *Anagrus* species involved.

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Introduction

Some years ago, one of the authors (G.V.) started to study egg parasitoids of leafhoppers (Cicadellidae), mostly in southern Italy. Efforts were made to collect members of *Anagrus* Haliday (Hymenoptera: Mymaridae) from wild and cultivated host plants, and possibly from known insect hosts. Most of the collected species belonged to the *atomus* species group as defined by Chiappini (1989). Their morphology and phenology were studied in relation to some agroecosystems (Viggiani, 1991; 2009; Viggiani *et al.*, 2003; 2004a; 2004b; Viggiani & Jesu, 2005; Matteucig & Viggiani, 2008; Velocci & Viggiani, 2008). Taxonomic discrimination of *A. atomus* (Linnaeus) and *A. ustulatus* Haliday (*sensu* Chiappini, 1989) was not confirmed by molecular analysis of ITS2 and COI, but in this complex a clade corresponding to *Anagrus ustulatus* from eggs of *Lindbergina aurovittata* (Douglas) on *Quercus ilex* L. was clearly distinct (Monti *et al.*, 2009). This evidence suggested a more in-depth morphological analysis and molecular characterization, integrated with extensive biological data (Nugnes, 2011; Nugnes *et al.*, 2011). In this paper the *Anagrus* species reared from *L. aurovittata* on *Q. ilex* is recognized and described as a new species belonging to the *atomus* species group.

Anagrus presently includes 92 valid species (Noyes, 2013); only 19 of them are included in the *atomus* species group of *A.* (*Anagrus* Haliday). The *atomus* group was defined in different ways (Graham, 1982; Chiappini, 1989; Chiappini *et al.*, 1996), but the main discriminating character is the presence of only 3 multiporous plate sensilla (mps) on the antennal club of females.

Materials and Methods

Leaves of *Q. ilex* were randomly collected in several locations of Campania (mostly in Portici, NA, and in Vietri sul Mare, SA) and in Basilicata (Rivello, PZ). In the laboratory the parasitised eggs of *L. aurovittata* were individually isolated with a small piece of leaf tissue in a microcapsule (diameter 15 and height 15 mm). The leafhopper host was previously identified according to features of the male genitalia, as illustrated by Vidano *et al.* (1990). Emerged parasitoids of *Anagrus* were slide-mounted in Canada balsam phenol. Samples of specimens caught by sticky yellow traps, placed in the *Q. ilex* woodland of Parco Gussone (Portici), from October 2011 to June 2013, were also slide-mounted. All the material was examined under a Zeiss Axiophot microscope and measurements were taken and given in µm. Terminology used in this article follows Gibson (1997), Huber (2012) and Debauche (1948) for forewing macrosetae.

From December 2009 to April 2010, 3 yellow sticky traps (Glutor,

13×24 cm) were installed at a distance of about 30 m from each other in a *Q. ilex* woodland at Portici (50 m elevation) and removed every two weeks. From October 2011 to June 2013 traps of the same type were placed in the same area, but removed weekly. In the laboratory each trap was examined, the adults of *Anagrus* and those of *L. aurovittata* were recorded.

Samples of 100 *Q. ilex* leaves were taken at random each week in the same woodland from November 2009 to April 2010. On each leaf the eggs (healthy and parasitised) and the young stages of *L. aurovittata* were recorded. Two samples, each of 50 leaves, were randomly taken on 2.x.2009 and 11.iii.2011 for evaluation of degree of infestation by *L. aurovittata* and the percentage parasitism of their eggs by *Anagrus*.

Adult emergence of *Anagrus* and *L. aurovittata* in the field was also followed by marking some eggs on *Q. ilex* leaves and examining them weekly.

Anagrus spp. examined for the morphometric analysis

Anagrus atomus (Linnaeus). From eggs of *Ficocyba ficaria* (Horvath) in leaves of *Ficus carica* L.: 7♀, Torrecuso (BN), 2.vii.2004, coll. A. Di Luca; 2♀, same place and collector, 8.vii.2004; 1♀, same place and collector, 12.vii.2004; 1♀, same place and collector; 1♀, Tramonti (SA), 13.vii.2004, same collector; 1♀, Torrecuso, 14.vii.2004, coll. A. Di Luca; 3♀, Tramonti, 21.vii.2004, coll. A. Di Luca; 3♀, same place and collector, 29.vii.2004; 1♀, same place and collector, 1.ix.2004. From eggs of *Zyginidia pullula* (Boheman) in leaves of *Zea mays* L.: 2 ♀, Brescia, 9.vii.2004, coll. I. Rigamonti; 7♀, same place and collector, 13.vii.2004; 1♀, Beregazzo con Figliaro (CO), 4.viii.2004, same collector; 1♀, Brescia, 13.viii.2004, same collector; 7♀, Rovellasca (CO), 13.viii.2004, same collector; 2♀, same place and collector, 25.viii.2004; 2♂, Tramonti, 26.vi.2004, from leafhopper egg in fig leaf, coll. G. Viggiani; 1♂, Torrecuso, 12.vii.2004, same host, coll. L. Rillo; 2♂, Brescia, 30.vii.2004, from leafhopper eggs in corn leaves, coll. I. Rigamonti; 4♂ Rovellasca, 4.viii.2004, same host and collector; 4♂, same place, host and collector, 25.viii.2004; 2♂, Portici, 19.vi.2007, from leafhopper eggs of *Eupteryx* sp. in *Salvia* leaves, coll. G. Matteucig; 1♂, same place, host and collector, 9.vii.2007.

Anagrus ustulatus Haliday (*sensu* Chiappini, 1989). From eggs of leafhoppers on bramble (*Rubus ulmifolius* L.) (Viggiani *et al.,* 2004b): 1♀, Rivello, 4.iv.2002, coll. G. Viggiani; 1♀, Portici, 4.iv.2002, same collector; 4♀, Rivello, 14.iv.2002, same collector; 1♀, same place and collector, 28.iv.2002; 1♀, Marcianise (CE), 2.v.2002, same collector; 1♀, Portici, 5.xi.2002, same collector; 3♀, Ghemme (NO), 18. xii.2002, coll. I. Rigamonti; 1♀, Domicella (AV), 25.ii.2004, coll. G. Viggiani; 2♀, Domicella, 7.iii.2004, same collector; 1♀, Domicella, 8.iii.2004, same collector; 2♀, Domicella, 22.iii.2004, same collector; 2♀, same place and collector, 22.iii.2004; 1♀, Domicella, 27.iii.2004, coll. A. Di Luca; 1♀, same place, 31.iii.2004, coll. G. Viggiani; 2♀, same place and collector, 2.iv.2004; 1♀, Napoli-S.Giovanni a Teduccio, 8.iv.2004, coll. R. Sasso; 1♀, Domicella, 13.iv.2004, coll. A. Di Luca; 1♀, Domicella, 17.iv.2004, coll. G. Viggiani; 2♀, Domicella, 20.iv.2004, same collector; 1♀, Napoli-S.Giovanni a Teduccio, 20.iv.2004, same collector; 2♀, Domicella, 24.iv.2004, coll. G. Viggiani; 1♀, same place and collector, 27.iv.2004; 1♀, same place and collector, 31.iv.2004; 1♀, Torre le Nocelle (AV), 3.v.2004, same collector; 1♀, Domicella, 6.v.2004, coll. A. Di Luca. From leafhoppers eggs on rose (*Rosa* sp.), probably of *Edwardsiana rosae* (Linnaeus): 1♀, Matraia (LU), 11.i.2005, coll. V. Mazzoni; 4♀, same place and collector, 24.i.2005; 1♀, same place and collector, 3.ii.2005; 3♀, same place and collector, 10.ii.2005; 1♀, same place and collector, 24.ii.2005; 7♀, same place and collector, 28.ii.2005. From eggs of leafhoppers on grapes (*Vitis vinifera* L.) (Viggiani *et al.,* 2004a): 1♀, Riparbella (PI), 1.vi.2002, coll. V. Mazzoni; 1♀, Napoli-S. Giovanni a Teduccio, 23.vii.2002, coll. R. Sasso; 1♀, Riparbella, 1.viii.2002, coll. V. Mazzoni; 21♀, S. Giorgio a Cremano (NA), 12.ix.2002, coll. R. Sasso; 2♀, same place and collector, 3.x.2002; 2♀, Riparbella, 21.x.2002, coll. V. Mazzoni; 1♀, S. Giorgio a Cremano, 27.x.2002, coll. R. Sasso; 1♀, same place and collector, 29.x.2002; 3♀, same place and collector, 5.xi.2002; 2♀, Riparbella, 8.xi.2002, coll. V. Mazzoni; 1♀, S. Giorgio a Cremano, 10.xi.2002, coll. R. Sasso; 1♀, Riparbella, 24.vi.2004, coll. V. Mazzoni; 1♀, same place and collector, 3.viii.2004; 4♀, same place and collector, 12.viii.2004; 9♀, same place and collector, 24.viii.2004; 3♀, same place and collector, 31.viii.2004; 11♀, same place and collector, 14.ix.2004; 4♀, same place and collector, 23.ix.2004;4♀, same place and collector, 5.x.2004. From leafhopper eggs on bramble: 3♂, Asciano (SI), 7.ii.2005, coll. V. Mazzoni; 2♂, Cisanello (PI), 10.ii.2005, same collector; 2♂, Asciano, 3.iii.2005, coll. same collector; 3♂, same place and collector, 7.iii.2005; 1♂, same place and collector, 14.iii.2005; 2♂, Cisanello, 14.iii.2005, same collector; 2♂, Matraia, 7.iii.2005, same collector; 4♂, same place and collector, 7.iv.2005; 1♂, same place and collector, 14.iv.2005. From leafhopper eggs on grape leaves: 2♂, S.Giorgio a Cremano, 5.ix.2002, coll. R. Sasso; 2♂, Riparbella, 9.ix.2002, coll. V. Mazzoni; 1♂, same place and collector, 21.x.2002; 2♂, S.Giorgio a Cremano, 28.x.2002, coll. R. Sasso; 1♂, Riparbella, 28.viii.2003, coll. V. Mazzoni; 1♂, same place and collector, 24.vi.2004; 1♂, same place and collector, 12.viii.2004; 1♂, same place and collector, 31.viii.2004; 6♂, same place and collector, 14.ix.2004; 3♂, same place and collector, 5.x.2004. From leafhopper eggs on rose leaves: 5♂, Matraia, 24.i.2005, coll. V. Mazzoni; 1♂, same place and collector, 3.ii.2005; 2♂, same place and collector, 10.ii.2005; 1♂, same place and collector, 24.ii.2005; 2♂, same place and collector, 28.ii.2005.

Results

Taxonomy

Anagrus lindberginae Nugnes et Viggiani, sp. n.

Holotype ♀, slide-mounted and labeled as follows: Italy. Campania, Portici (NA), Parco Gussone (40°48'45.66"N 14°20'46.12"E), from egg of *Lindbergina aurovittata* on *Quercus ilex*, 7.iii. 2003, coll. G. Viggiani. Paratypes: 4♀, Portici, 3. iii, 2003, same host and collector; 15♀, Portici, 7.iii. 2003, same host and collector; 1♀, Portici, 20.i.2010, same host, coll. F. Nugnes; 1♀, Portici, 12.i.2011, same host and collector; 1♀, Portici, 17.iii.2012, same host and collector; 1♀, Portici, 22.iii.2012, same host and collector; 1♀, Portici, 25.iii.2012, same host and collector; 1♀ and 1♂, Portici,12.ii.1985, from eggs of *L. aurovittata* in leaves of *Myrtus communis*, coll. G. Viggiani. The paratypes are all slide-mounted.

Additional material: From egg of *L. aurovittata* in leaves of *Q. ilex*: 1♀, Portici, 18.ii.2006, coll. G. Viggiani; 1♀, same place, 11.iii.2011, coll. G. Viggiani. From leafhopper eggs, probably of *L. aurovittata*, in leaves of *Q. ilex*: 1♀, Castellaro (IM), 4.iii.1989, coll. A. Arzone; 1♂, Pino Torinese (TO), 15.ii.1990, same collector; 2♀, Castellaro, 28.v.1990, same collector. From eggs of *L. aurovittata* in leaves of *Myrtus communis* L. 5♀, Portici,7.iii.2003, coll. G. Viggiani; 2♀, 14.iii.2005, same place and collector,; 1♀, 15.iii.2005, same place and collector. From yellow sticky traps: 13♀, Portici, 22-29.i.2003, coll. G. Viggiani; 5♀, same place and collector, 5.ii.2003; 1♂, same place and collector, 12.ii.2003; 1♀, same place and collector, 12.ii.2003; 12♀, same place and collector, 5.iii.2003; 6♀, same place and collector, 26.iii.2003; 1♂, same place and collector, 19.xii.2011; 1♂, same place and collector, 16.i.2012; 1♂, same place and collector, 28.i.2012; 1♂, same place and collector, 26.iii.2012; 1♂, same place and collector, 9.iv.2012; 1♂, same place and collector, 27.xi.2012. All specimens of the additional material are slide-mounted.

Holotype, 3 ♀ paratypes and all additional material are deposited in the entomological collection of the Dipartimento di Agraria dell'Università degli Studi Federico II, Portici, Napoli, Italia; 2♀ paratypes (Portici, 7.iii. 2003, from egg of *Lindbergina aurovittata* on *Quercus ilex*, 7.iii. 2003, coll. G. Viggiani) in the National History

Museum, London, England, U.K.; 2♀ paratypes (Portici, 7.iii. 2003, from egg of *Lindbergina aurovittata* on *Quercus ilex*, 7.iii. 2003, coll. G. Viggiani) in the University of California, Riverside, USA; 2♀ paratypes (Portici, 7.iii. 2003, from egg of *Lindbergina aurovittata* on *Quercus ilex*, 7.iii. 2003, coll. G. Viggiani) in the National Museum of Natural History, Washington, D. C. and 2♀ paratypes (Portici, 7.iii. 2003, from egg of *Lindbergina aurovittata* on *Quercus ilex*, 7.iii. 2003, coll. G. Viggiani) in Canadian National Collection of Insects, Ottawa, Ontario.

Diagnosis

Female. Brown, head and pronotum darker. Antenna (scape, pedicel, F1-F4), scutellum and frenum, and legs, yellowish or light brown. Wings with infuscation on the area behind the venation. Body length: 400-500 µm (mean: 465 µm; SD: ±47.4; n=10). Head wider than high (1.25). Antenna (Figure 1A) with scape as wide as pedicel, but longer (1.8); F1 slightly longer than wide and narrow, about half of pedicel, F2 longer than F1 (2.16) and subequal to F4; F3 slightly shorter; F5 slightly wider than the previous segment and shorter than F6; club around twice the length of F6. Antennal segments with sparse setae, increasing in density from scape to club; F5 and F6 with one-two mps; club with 3 mps.

Mesosoma shorter than metasoma (ratio: 0.732; SD: ±0.0674; n=10). Pronotum with subpolygonal sculpture. Mesoscutum with mid lobe about as long as wide, with weakly raised sculpture, without setae. Forewing (Figure 1B) longer than body (mean: 749 µm; SD: ±48.6; n=10), (length/width ratio: 8.76 SD: ±0.7211; n=10); venation as in Figure 1C; ratio of distal macrochaeta length/proximal macrochaeta length variable, 2.72-7.20 (mean: 3.83: SD: ±1.008; n=20); disc at broadest part with 2-4 longitudinal rows of setae above an oval hairless area; longest marginal cilia/the maximum discal width ratio: 3.518 (SD: ±0.2959; n=10). Hind wing with a row of small setae along the posterior margin and an incomplete row of 4-6 setae on the distal half of the anterior margin. Legs: fore tibia (Figure 1D) shorter than middle and hind tibiae (average ratio: 1:1.3:1.5; n=20); tarsomeres, 2.3 times as long as wide; basitarsomere of foreleg slightly longer.

Metasoma sublaterally with two groups of two setae on terga IV-VII, and one group of 2 setae on tergum VIII; cercal plate with 3 subequal long setae and 1 about one half their length. Ovipositor slightly exserted beyond apex of gaster. Ratio of total ovipositor length/length of fore tibia (Figure 1D, E): 1.4-1.6 (mean: 1.52; SD: ±0.064; n=36). Ratio of length of the ovipositor/length of third valvula: 1.7-2.2 (mean: 2.04; SD: ±0.144; n=10); third valvula with one short subapical seta.

Male. Similar to female in colour, but a little darker. Body length: 400-500 µm. Antenna (Figure 1F) 13-segmented, with transversely ridged scape 2.02.5 times as long as wide, pedicel as long or slightly shorter than F1, flagellar segments with F1 shorter than F2, subsequent segments subequal, 2 times as long as wide, with last three segments a little longer. Flagellar segments with sparse setae and each with 2-3 mps. Male genitalia (Figure 1G) as in *A. atomus* (Viggiani 1970), with the aedeagus body a little longer than the apodemes. Length: 82-105 µm (mean: 93; SD: ±6.5; n=9).

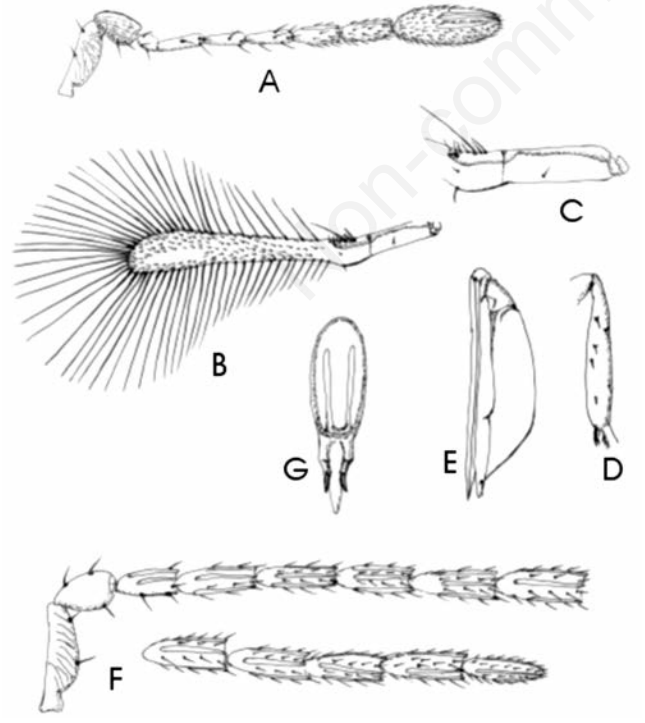
Etymology. The specific name *lindberginae* refers to the leafhopper host genus.

Distribution. The new species is recorded from Campania, Liguria and Piedmont in Italy. The *A. atomus* referred by Bosco & Arzone (1991) as parasitoid of *Lindbergina* spp. is to be considered *A. lindberginae* (voucher specimens examined by G.V.).

Remarks. In the key to Holarctic species of *Anagrus* (Chiappini *et al.*, 1996), *A. lindberginae* goes to the same couplet as *A. longitibialis* Donev, the only other known European species that has the same ovipositor/fore tibia ratio (1.5-1.6), but A. *longitibialis* differs by having a mps on both F3 and F4. However, it is *A. ustulatus sensu* Chiappini that the new species resembles the most. It differs morphologically from this species by the ratios ovipositor length/fore tibia and ovipositor length/third valvula.

The most common species of the *A. atomus* group allied to *A. lindberginae* are *A. atomus* and *A. ustulatus* (*sensu* Chiappini, 1989). Morphometric data on females of these *Anagrus* species were given by Chiappini (1987). According to Chiappini *et al.* (1996) females of *A. atomus* can be distinguished by the following combination of features: club with three mps, F3 without mps, F4 with one mps; ovipositor/fore tibia ratio about 2.0; mesoscutum without setae; forewing with three irregular rows of discal hairs in basal half, and three or four rows anterior to hairless area, hairless area at broadest part of forewing short, FWL/FWW <10. In the description of the neotype of *A. atomus*, Chiappini & Triapitsyn (2007) add other characters to the diagnosis of *A. atomus*: F2 a little longer than F3; club a little longer than two preceding segments combined; forewing 6.8 times as long as wide; distal macrochaeta about 2.5 times the length of the proximal macrochaeta.

Anagrus ustulatus Haliday (1833, p. 347) was described as follows: Sp. 3. A. ustulatus. *Fuscus antennis thoracis disco pedibusque ferrugineis, alis hyalinis*. ♂ (Long. 0.03; alar. 0.08.). Precedentibus brevior, colore obscuriore; alae ut in *A. atomo*. Graham (1982, p. 201) stated that *of the seven specimens that stand under this name in Haliday's collection, but all except the first two (Nos. 70 and 71) are females. No 70 agrees with the original description and is now designed LECTOTYPE*. He stated that the females were *clearly* conspecific with the male lectotype and did not accept the synonymy of *A. ustulatus* with *A. atomus* proposed by Debauche (1948). In his key Graham (1982, p. 198) stated that *ustulatus* shows *forewing very broad for the genus 5.7-6.1 times as long as broad and with 8-9 longitudinal rows of hairs in its distal part*. Chiappini (1989) recognised that her *Anagrus* sp. obtained from leafhoppers on bramble and rose is conspecific with *A. ustulatus*. However, that species does not fit with the characters given by Graham in his key. In *A. ustulatus sensu* Chiappini the ratio of forewing length/forewing width is 8.237 (9.400-7.200) and the rows of hairs on



Figures 1. *Anagrus lindberginae* sp. n. Female. A) antenna; B) forewing; C) details of venation; D) fore tibia; E) ovipositor. Male. F) antenna; G) genitalia.

the discal area are 4-5. But according to Graham (1982, p. 201) the genitalia of the lectotype male of *ustulatus* are *unlike those of* atomus *but similar to the type found in the* incarnatus *species-group;* according to Chiappini (1989, p. 104) the genitalia of *A. ustulatus are typical of* atomus *group*. That does not help to characterize the species properly. The situation is worse for the female of *A. ustulatus*, which Graham (1982) considered a *species sola* and did not include in the *atomus* species-group. In fact, of the 5 female specimens standing under this name in Haliday collection the two numbered 72 and 73 belong to *A. incarnatus* Haliday (Chiappini and Triapitsyn, 2007). In conclusion, the validity of *A. ustulatus* Haliday remains uncertain. For an attempt at clarification the genitalia of the male lectotype and all females under this name in Haliday's collection need to be properly slide-mounted and studied. One of the present authors (G.V.) is doing this.

Our morphometric data (Tables 1-3) on several populations of *A. atomus* and *A. ustulatus sensu* Chiappini show that morphological discrimination of the female may be substantially based only on the presence or absence of a sensory ridge on F4; intermediate forms are rather rare. The other characters reported by Chiappini and Triapitsyn (2007) (ratio of F2/F3; ratio of club length/F5+F6 length; ratio of forewing length/forewing width; ratio of distal macrochaeta length/proximal macrochaeta length; number of hair rows on forewing disc, extension of hairless area at broadest part of forewing; ovipositor/fore tibia ratio) are widely variable and overlapping.

Very limited information is available about the morphological characters of males of the *atomus* group. Some measurements on the male genitalia are reported by Chiappini and Mazzoni (2000) and Floreani *et al.* (2006). They show no significant differences for distinguishing *A.*

Table 1. Morphometric measurements of *Anagrus* antenna (20 females) (in µm).

Measure	Length (mean±SD)	Width (mean±SD)	Length (mean±SD)	Width (mean±SD)
	A. atomus from corn leaves		*A. ustulatus* from bramble	
Scape	80±5.1	24±2.2	70±5.3	24±3.0
Pedicel	41±2.0	27±2.3	39±3.2	27±2.4
F1	18±1.7	15±0.0	17±2.2	13±2.5
F2	48±2.9	13±2.0	39±4.2	11±2.2
F3	44±3.2	11±1.4	34±4.9	11±1.7
F4	52±3.7	15±1.8	40±4.3	12±2.3
F5	54±4.1	16±2.2	45±4.5	17±2.4
F6	56±3.5	20±1.7	50±5.1	19±2.6
Club	100±3.2	32±2.9	99±7.2	31±3.1
	A. atomus from fig leaves		*A. ustulatus* from grape leaves	
Scape	87±6.3	25±1.6	68±4.1	23±2.5
Pedicel	38±2.7	27±2.9	38±2.5	25±1.3
F1	16±2.3	11±2.3	16±2.9	13±2.1
F2	37±3.8	12±2.3	35±2.8	11±1.8
F3	33±4.6	10±1.3	29±2.2	10±0.5
F4	44±5.5	15±1.3	36±3.3	12±2.2
F5	48±3.7	15±1.6	43±3.4	16±2.3
F6	50±4.3	19±1.7	48±3.0	19±2.3
Club	98±5.1	30±2.9	95±5.3	31±2.3
	A. lindberginae		*A. ustulatus* from rose leaves	
Scape	71±3.1	25±0.7	69±3.5	25±0.0
Pedicel	44±3.4	26±2.3	41±2.6	28±2.3
F1	20±1.1	14±1.8	17±2.2	13±2.0
F2	47±2.9	14±2.9	39±4.1	12±2.0
F3	40±4.4	11±1.4	33±3.6	11±1.3
F4	46±3.7	14±1.9	39±3.8	13±2.1
F5	51±4.0	15±1.5	46±3.5	19±2.1
F6	53±2.5	19±1.6	49±2.2	20±6.2
Club	103±4.3	32±8.7	100±3.5	32±3.0

Table 2. Morphometric measurements (mean ±SD) of *Anagrus* forewing (20 females).

	FWL	DW	FL	FWL/DW	FL/DW	DML/PML
A. atomus from corn leaves	535±23.0	57±5.5	175±9.4	9.40±0.644	3.09±0.326	4.05±0.614
A. atomus from fig leaves	480±32.5	55±4.8	163±9.7	8.79±0.425	2.97±0.216	2.61±0.368
A. lindberginae	563±34.3	66±5.9	209±10.5	8.55±0.586	3.17±0.328	3.83±1.008
A. ustulatus from bramble	508±44.3	68±10.1	180±15.7	7.60±0.765	2.70±0.422	3.23±0.553
A. ustulatus from grape leaves	439±27.5	54±5.0	159±7.6	8.26±0.645	2.92±0.290	3.04±0.605
A. ustulatus from rose leaves	524±24.8	71±1.4	208±12.4	7.42±0.394	2.94±0.253	2.98±0.420

DML/PML, distal macrochaeta length/proximal macrochaeta length; DW, discal width; FL, fringe length; FL/DW, fringe maximum length/discal width; FWL, forewing length; FWL/DW, forewing length/discal width.

atomus from *A. ustulatus sensu* Chiappini. Our data concerning the antenna, forewing, male genitalia of above-mentioned species and those of *A. lindberginae* (Tables 4-6) confirm the present impossibility to distinguish their males on a morphological basis.

Another allied species, and possibly a junior synonym of *A. ustulatus sensu* Chiappini, is *A. erythroneurae* Trjapitzin and Chiappini (De León *et al.* 2008) although they were shown to differ genetically.

At present, females of the European species of the *atomus* group can be keyed as follows:

1. Antenna with a mps on F3 and/or F4 2
- Antenna without a mps on F3 and/or F4 3
2. Antenna with a mps on F3 and F4; ovipositor length/fore tibia length ratio 1.5-1.6 ..... *A. longitibialis* Donev
- Antenna without a mps on F4; ovipositor/fore tibia ratio 1.9-2.0 ..... *A. atomus* (Linnaeus)
3. Ovipositor length/fore tibia ratio 1.8-2.2; fore tibia length/third valvula length ratio 1.26-1.60 ..... *A. ustulatus sensu* Chiappini (*nec* Haliday, 1833)
- Ovipositor length/fore tibia length ratio 1.4-1.6; fore tibia length /third valvula length ratio 1.9-2.1 ..... *A. lindberginae* Nugnes et Viggiani

The species *A. ustulatus sensu* Chiappini (1989) should be referred to *A. parvus* Soyka (1955). At present *Anagrus ustulatus* Haliday 1833, based on a lectotype male, revised by Graham (1982) and Chiappini (1989), can not be definitely linked to any female species of the *atomus* group of *Anagrus*.

Table 3. Morphometric measurements (mean±SD) of the *Anagrus* ovipositor (20 females).

	OL	FTL	OL/FTL	V3L	FTL/V3L
A. atomus from corn leaves	236±8.6	120±6.1	1.97±0.113	82±4.7	1.45±0.085
A. atomus from fig leaves	227±18.3	111±9.0	2.03±0.102	83±5.7	1.34±0.105
A. lindberginae	194±11.0	125±5.5	1.54±0.093	61±3.3	2.02±0.064
A. ustulatus from bramble	214±15.5	109±11.0	1.97±0.114	74±2.6	1.46±0.117
A. ustulatus from grape leaves	208±10.2	99±4.1	2.10±0.092	73±4.7	1.36±0.099
A. ustulatus from rose leaves	218±9.5	113±5.8	1.91±0.091	74±4.3	1.49±0.112

FTL, fore tibia length; OL, ovipositor length; OL/FTL, ovipositor length/fore tibia length; OL/V3L, ovipositor length/third valvula length; V3L, third valvula length.

Table 4. Morphometric measurements of *Anagrus* male antenna (16 *A. atomus*, 9 *A. lindberginae*, 20 *A. ustulatus* from bramble, 20 *A. ustulatus* from grape leaves, and 11 *A. ustulatus* from rose leaves).

	Length (mean±SD)	Width (mean±SD)	Length (mean±SD)	Width (mean±SD)	Length (mean±SD)	Width (mean±SD)
	A. atomus		*A. ustulatus* from bramble		*A. ustulatus* from rose leaves	
Scape	62±4.5	23±2.9	59±2.8	23±2.3	61±3.7	23±3.0
Pedicel	38±35	30±2.2	40±1.9	29±1.2	40±0.0	29±0.7
F1	35±4.8	21±3.1	31±3.1	21±1.6	29±4.7	20±1.9
F2	46±8.5	18±2.9	39±4.2	19±2.1	37±4.7	18±2.3
F3	47±7.1	19±2.5	39±4.2	19±1.7	37±5.4	18±2.0
F4	47±6.5	19±2.0	39±3.5	18±2.5	38±3.9	17±2.5
F5	47±6.3	18±2.6	40±3.8	19±2.6	38±4.2	19±2.8
F6	49±6.0	19±2.9	42±3.0	19±3.1	40±3.9	19±3.2
F7	50±5.3	20±3.7	42±3.0	19±2.8	41±2.5	19±3.2
F8	49±5.2	20±2.7	43±3.4	21±3.1	42±2.5	20±2.3
F9	51±5.0	21±3.5	44±2.4	21±3.0	44±3.9	20±3.6
F10	51±4.5	21±3.1	45±1.9	22±3.2	46±2.3	21±3.0
F11	54±5.5	20±3.6	49±4.2	20±2.3	48±4.0	19±2.2
	A. lindberginae		*A. ustulatus* from grape leaves			
Scape	62±5.6	21±2.5	57±3.0	20±1.5		
Pedicel	38±2.6	14±4.1	35±2.6	27±2.7		
F1	34±5.3	18±2.5	29±2.6	19±2.0		
F2	43±7.9	16±1.8	37±5.0	16±2.2		
F3	43±7.0	16±1.8	37±4.1	17±2.4		
F4	45±7.0	15±1.7	37±3.4	16±2.3		
F5	45±6.6	15±1.6	38±4.1	17±2.4		
F6	45±6.1	16±1.8	39±3.7	18±2.7		
F7	46±6.2	16±2.5	40±3.1	18±2.7		
F8	46±6.1	18±3.0	40±3.6	18±3.5		
F9	46±5.8	19±3.7	43±3.9	19±3.2		
F10	48±4.6	19±3.6	43±2.8	19±3.9		
F11	52±7.0	17±3.8	45±3.5	18±2.7		

Host and parasitoid ecology

In Italy, the leafhopper *L. aurovittata* overwinters as an egg in the leaf of the evergreen plants *Q. ilex*, *Q. suber* (Vidano et al, 1990), *M. communis* and *R. ulmifolius* (Viggiani *et al.*, 2004b; Matteucig and Viggiani, 2008), but also as an adult, as recorded below (Figures 2-4). The most common winter host of *L. aurovittata*, at least in Campania, is *Q. ilex*. During spring the species completes one generation and new adults leave the winter hosts and spread to plants with deciduous leaves such as some *Quercus* spp. and *Castanea* spp. (Viggiani, 1991; 2009). From summer to late autumn the leafhopper can complete more generations. The leafhopper adults then go back on the overwintering hosts and oviposit in subepidermic slits on the leaves, normally by laying single eggs.

The parasitoid *Anagrus lindberginae* shows a long diapause as a young larva in the host egg (Figure 5), starting from March-April.

From October-November (Figure 6) this stage completes its development in a pupa followed by the adult emergence. These phenological stages of *A. lindberginae* are synchronized with the presence of host

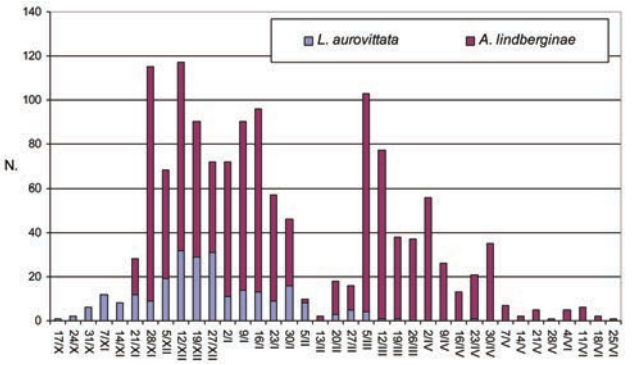


Figure 3. Captures of *L. aurovittata* and *Anagrus* by yellow sticky traps disposed in *Q. ilex* woodland in Portici (Parco Gussone) from October 2011 to June 2012.

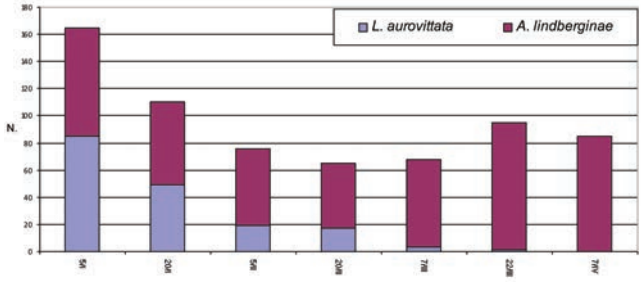


Figure 2. Captures of *L. aurovittata* and *A. lindberginae* by yellow sticky traps disposed in a *Q. ilex* woodland (Portici, Parco Gussone) from December 21, 2009 to April 7, 2010.

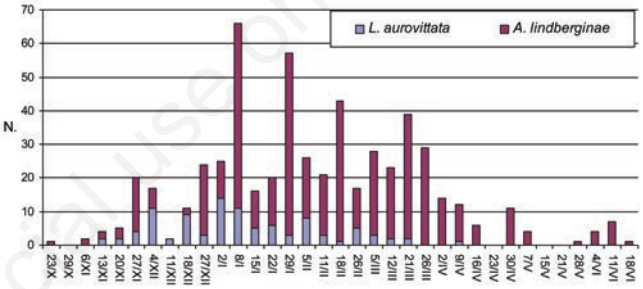


Figure 4. Captures of *L. aurovittata* and *Anagrus* by yellow sticky traps disposed in *Q. ilex* woodland in Portici (Parco Gussone) from October 2012 to June 2013.

Table 5. Morphometric measurements (mean±SD) of *Anagrus* male forewing (16 *A. atomus*, 9 *A. lindberginae*, 20 *A. ustulatus* from bramble, 20 *A. ustulatus* from grape leaves, and 11 *A. ustulatus* from rose leaves).

	FWL	DW	FL	FWL/DW	FL/DW	DML/PML
A. atomus	561±43.4	71±5.4	194±16.7	7.82±0.653	2.77±0.339	4.11±0.960
A. lindberginae	603±0.8	86±8.6	224±11.3	6.99±0.584	2.60±0.273	3.56±0.654
A. ustulatus from bramble	533±30.1	80±7.2	214±10.9	6.68±0.481	2.69±0.255	3.06±0.768
A. ustulatus from grape leaves	502±42.6	76±10.4	195±16.4	6.61±0.503	2.56±0.228	3.34±0.412
A. ustulatus from rose leaves	550±35.9	83±4.5	221±10.8	6.69±0.566	2.61±0.115	3.05±0.366

DML/PML, distal macrochaeta length/proximal macrochaeta length; DW, discal width; FL, fringe length; FL/DW, fringe maximum length/discal width; FWL, forewing length; FWL/DW, forewing length/discal width.

Table 6. Morphometric measurements (mean±SD) of *Anagrus* male genitalia (16 *A. atomus*, 9 *A. lindberginae*, 20 *A. ustulatus* from bramble, 20 *A. ustulatus* from grape leaves, and 11 *A. ustulatus* from rose leaves).

	GL	PL	PW	EL	EBL	EAL
A. atomus	91±5.1	52±5.5	25±2.5	82±3.8	43±1.7	38±3.0
A. lindberginae	93±9.2	48±6.2	24±1.7	86±5.6	49±3.8	36±4.1
A. ustulatus from bramble	89±5.4	48±3.7	25±1.3	82±5.6	47±4.2	35±3.8
A. ustulatus from grape leaves	89±9.8	45±4.0	23±2.3	81±8.1	49±6.4	33±2.9
A. ustulatus from rose leaves	90±5.4	48±4.2	24±3.0	83±4.5	48±2.6	35±2.7

AAL, aedeagus apodeme length; AL, aedeagus length; ABL, aedeagus body length; GL, Genitalia length; PL, phallobase length; PW, phallobase width.

new eggs. The parasitoid oviposits in the progressively available host eggs and their young stages develop during winter, when most of the adults emerge (Figures 2-4). They can oviposit in the remaining, left over healthy host eggs, but most of their progeny will start a long diapause period as young larvae from spring to fall. *Anagrus lindberginae* completes at least one generation from late autumn to early spring.

Over several years it has been confirmed that the population of *A. lindberginae* is represented almost exclusively by females; males are very rare (Viggiani *et al.,* 2003). In the woodland of Parco Gussone (Portici) the percentage of *Q. ilex* leaves with eggs of *L. aurovittata* ranged from 66-54% (Figure 7); that of the not-parasitised eggs varies from 6.5-37.3%.

Discussion and Conclusions

The concept of the *atomus* group has changed somewhat (Chiappini, 1989; Chiappini *et al*., 1996; Chiappini & Mazzoni, 2000). At present this group includes species with 3 mps on the antennal club of females and the genitalia of males, with digiti spines straight or bent. Among the Holarctic species of *Anagrus*, only 8 species are included in the *atomus* group. The genotype species, *A. atomus,* is widespread and rather well characterized (Chiappini & Triapitsyn, 2007), but the identity of the allied species *A. ustulatus* still remains questionable for the following reasons: i) the poor original description is based on a male, which was designed lectotype (Graham, 1982); ii) no female in the Haliday collection can be definitely associated with the lectotype male; in fact some specimens considered *clearly conspecific* by Graham (1982) belong to *A. incarnatus* (Chiappini & Triapitsyn 2007); iii) the interpretation of *A. ustulatus* given by Chiappini (1989) is uncertain; iv) the very small morphological differences between *A. atomus* and *A. ustulatus sensu* Chiappini (presence or absence of a mps on F4) are not supported by the molecular data (Monti *et al.*, 2009). However Cargnus & Pavan (2007) have found enzymatic differences between females of *A. atomus* and *A. ustulatus* reared from the leafhoppers on bramble and grape. Floreani *et al.* (2006), using the cuticular hydrocarbon analysis, found two distinct profiles for *A. atomus* and *A. ustulatus*, classified according to the morphological characters given by Chiappini (1989).

The new species *A. lindberginae* appears morphologically clearly distinguishable among the *atomus* group species, supported by the molecular data (Monti *et al.*, 2009; Nugnes, 2011). As in a few other species or populations of *Anagrus*, *A. atomus* (MacGill, 1934; Choudhury & Copland 2003), *A. delicatus* (Cronin & Strong, 1996), and *A. takeyanus* (Chiappini *et al*., 1996), the reproduction of *A. lindberginae* takes place through thelytokous females. The life cycle is well syncronized with that of the host.

In the system *Q. ilex - L. aurovittata - A. lindberginae* two main biological phenomena are involved: migration and diapause. The leafhopper migration in spring from the evergreen hosts to plants with deciduous leaves for reproduction during summer and autumn avoids unfavorable conditions. The larval diapause of *A. lindberginae* allows the parasitoid to survive during a long period in its host's absence. At present, parasitised eggs of *L. aurovittata* by *A. lindberginae* were not recorded in any of the known deciduous host plants of this leafhopper.

A similar case was reported by Tsukada (1999). In Japan, the andromeda lace bug *Stephanitis takeyai* Drake et Maa (Heteroptera: Tingidae), shows a seasonal host-plant alternation between its main host plants, the evergreen *Pieris japonica* and the deciduous *Lyonia ovalifolia*. In some sites where the latter host is rare, the tingid reproduces on *P. japonica* all year around. The seasonal alternative host for *S. takeyai* seems derived from the ancestral non-alternating life cycle. In places were the insect host develop only one generation a year, the egg parasitoid of the tingid, *Anagrus takeyanus* Gordh and Dunbar, enters in a summer diapause.

Figure 5. Eggs of *L. aurovittata* with diapausing larvae (red orange) of *A. lindberginae*.

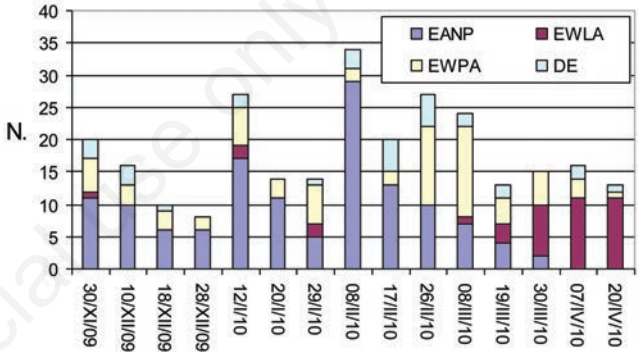


Figure 6. Monitoring of the eggs of *L. aurovittata* and their parasitism by *A. lindberginae* from November 2009 to April 2010 (Portici, Parco Gussone). Abbreviations: DE=dried eggs. EANP=eggs of *L. aurovittata* apparently not parasitised. EWLA=eggs with larva of *A. lindberginae*. EWPA=eggs with pupa of *A. lindberginae*.

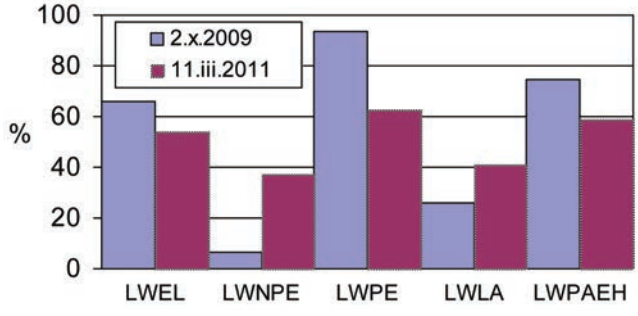


Figure 7. Percentage of *Q. ilex* leaves with eggs of *L. aurovittata* and their rate of parasitism by *A. lindberginae* (Samplings of 2 October 2009 and of 11 March 2011). Abbreviations. LWEL=leaves with eggs of *L. aurovittata*; LWNPE=leaves with non-parasitised eggs of *L. aurovittata*; LWPE=leaves with eggs parasitised by *A. lindberginae*; LWLA=leaves with larvae of *A. lindberginae* in the eggs of *L. aurovittata*; LWPAEH=leaves with pupae of *A. lindberginae* and adult exit hole in the eggs of *L. aurovittata*.

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