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## New species and new records of *Aphelinus* Dalman (Hymenoptera: Chalcidoidea: Aphelinidae) from Lagodekhi Reserve (Sakartvelo - Georgia), with diversity and distribution along an elevational gradient

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**Abstract:** The aim of the present study was to investigate species diversity and distribution of *Aphelinus* species in an elevational gradient in the Lagodekhi Reserve (Sakartvelo - Georgia) throughout a growing season. Two species of *Aphelinus* Dalman, 1820 (Hymenoptera: Aphelinidae), *A. humilis* Mercet and *A. thomsoni* Graham, are recorded for the first time from Georgia and the Caucasus and two species (*A. lagodekhiensis* **sp. nov.** and *A. sugonjaevi* **sp. nov.**) are described as new to science. To facilitate species identification we have developed a key to the females of all 24 species of *Aphelinus* currently known from the Middle East and the Caucasus. Both species richness and abundance of *Aphelinus* increased with increasing elevation, although no statistically significant relationship was found. Maximum diversity and abundance were observed in July, and this was more pronounced at higher elevations.

**Key words:** New species, *Aphelinus*, taxonomy, biodiversity, Georgia

### 1. Introduction

The family Aphelinidae (Hymenoptera, Chalcidoidea) currently includes 43 genera and 1168 species (Noyes, 2017) placed in five subfamilies (Aphelininae, Calesinae, Coccophaginae, Eretmocerinae, and Eriaphytinae) according to the recent classification by Heraty et al. (2013). Most of the species of Aphelinidae are parasitoids of Hemiptera while others also parasitize upon Orthoptera, Hymenoptera, Diptera, and Lepidoptera (Yasnosh, 1995). The genus *Aphelinus* Dalman (Aphelininae) includes the parasitoid species of sap-sucking aphids (Aphidomorpha) and hence has great potential in biocontrol applications (Nikol'skaya and Yasnosh, 1966; Chervonenko, 1997; Yasnosh, 2002). Species diversity and distribution within this genus is relatively well known. In particular, among the 98 described species worldwide, 37 and 15 species are known from Europe and the Caucasus, respectively (Japoshvili and Abrantes, 2006; Japoshvili and Karaca, 2009; Japoshvili and Hansen, 2014; Hawro et al., 2015; Lopes et al., 2016; Noyes, 2017). From Georgia, 14 species have hitherto been recorded, including *Aphelinus abdominalis* (Dalman), *A. asychis* Walker, *A. atriplicis* Kurdjumov, *A. babaneuri* Japoshvili, *A. chaonia* Walker,

*A. brunneus* Yasnosh, *A. flaviventris* Kurdjumov, *A. fusciscapus* (Förster), *A. hordei* Kurdjumov, *A. kurdjumovi* Mercet, *A. mali* (Haldeman), *A. subflavescens* (Westwood), *A. varipes* (Förster), and *A. yasnoshae* Japoshvili (Japoshvili and Karaca, 2009).

The aim of this paper is to describe two additional species of *Aphelinus* and provide new data on the diversity and the temporal and spatial distribution of *Aphelinus* species collected from a recent field survey in the Lagodekhi Nature Reserve (LR) (Georgia). To facilitate species identification, we also provide a key of all 24 *Aphelinus* species currently known from the Middle East and Caucasus regions.

### 2. Materials and methods

The LR is the oldest protected territory in the Caucasus, established in 1912 in the extreme northeastern part of Georgia. It extends at an altitude of 590–3500 m and is one of the world's best-preserved, primitive areas with diversity of natural landscapes (APA, 2017).

Seven Malaise traps were set up on an elevational transect in the LR, Kudigori mountain range, at the following sites: H1 - mountain low zone, mixed mountain

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forest, with dominant *Fagus-Carpinus* mixed forest, Fageto-Carpinetum-festucosum, N41.8524833, E46.2877667, 666 m; H2 - mountain middle zone, mixed mountain forest, with dominant *Fagus* mixed forest, Fagetum-Nudum, N41.8558500, E46.2927333, 847 m; H3 - mountain middle zone, mixed mountain forest, with dominant *Fagus* mixed forest, Fageto-galiosum, N41.8714667, E46.3115333, 1351 m; H4 - mountain upper zone, broad-leaved upper montane forest, with dominant *Fagus-Acer*, with *Rubus* underbrush, Fagetum-Acereto-rubosum, N41.8827333, E46.3218500, 1841 m; H5 - mountain upper zone, broad-leaved upper montane forest, with dominant *Acer*, Acereto-Rubosum, N41.8855833, E46.3241167, 1902 m; H6 - subalpine zone, subalpine *Juniperus*, Juniperetum, N41.8980500, E46.3338833, 2230 m; and H7 - alpine zone, mainly grassland, Alchemilletum, N41.9061833, E46.3334000, 2559 m. At each point we chose small, naturally open areas/forest edges with dense herbaceous vegetation for sampling.

Samples were collected during 8 months, from April to November of 2014. However, the period of sample collection was shorter in alpine and subalpine areas (from May to October) due to reduced vegetation time at higher elevations. The Malaise traps were checked every 10 ( $\pm$ 2) days and the specimens were placed in 96% ethanol. The Hymenoptera were later sorted, dried, mounted, and labeled according to the method given by Noyes (2017).

We used terminology according to Nikol'skaya and Yasnosh (1966), Graham (1976), Hayat (1998), and Yasnosh (1963, 1978, 2002) and the species description layout following Hopper et al. (2012). The following abbreviations were used in the text: f, female; ff, females; m, male; F1, F2, etc. first funicle segment, second funicle segment, etc.; FV, minimum frontovertex width. A binocular stereo microscope, MICROS" model: MS1107/MZ1280/MC1280, was used for identification. Digital images were taken using a Micros stereo microscope and Leica DM1000, with photo camera Sony nex3. Focus stacking was done using the automontage software Combine ZM (Hadley, 2008) and images were corrected using Adobe Photoshop CS4.

Synonymy, diagnoses, and taxonomic remarks are provided only for new species and new records, while for other species such information can be found in Nikol'skaya and Yasnosh (1966), Graham (1976), Japoshvili and Karaca (2009), and Noyes (2007). New records for Georgia and the Caucasus are indicated with an asterisk and the vouchers and types are deposited in the Entomological Collection of the Agricultural University of Georgia, Tbilisi, Georgia.

For each sampling plot, we assessed the richness of the vascular plants (flora) using counts in four randomly chosen  $10 \times 10$  m<sup>2</sup> plots within an area of 2500 m<sup>2</sup> around each Malaise trap. Plant inventories were made three times

(seasonally) to investigate the relationship between plant and insect diversity. Complete presence or absence data on plant species can be found in Mumladze et al. (2017). Here we only used the data on plant diversity to investigate its effect on the richness and composition of *Aphelinus* species.

### 3. Results and discussion

#### 3.1. Check-list of *Aphelinus* species recorded from Lagodekhi reserve

##### 1. *Aphelinus abdominalis* (Dalman, 1820)

**Material examined:** 1f, 12–24.iv.2014; 2ff, 24.iv.–5.v.2014; 1f, 5–15.v.2014; 4ff, 15–24.v.2014; 1f, 24.v.–4.vi.2014; 4ff, 15–25.vi.2014; 3ff, 25.vi.–5.vii.2014; 1f, 4–14.ix.2014, [#H1], leg. Japoshvili & Kirkitadze; 1f, 5–15.vii.2014; 1m, 15–24.v.2014, [#H2], leg. Japoshvili & Kirkitadze; 3ff, 24.v.–4.vi.2014; 1f, 5–15.vii.2014; 12ff, 15–25.vii.2014; 1f, 5–15.viii.2014, [#H3], leg. Japoshvili & Kirkitadze; 1f, 24.v.–4.vi.2014; 2ff, 4–14.vi.2014; 1f, 15–25.vi.2014; 3ff, 25.vi.–5.vii.2014; 4ff, 5–15.vii.2014; 2ff, 15–25.vii.2014; 1m, 5–15.viii.2014; 3ff, 15–25.viii.2014; 2ff, 25.viii.–4.ix.2014; 1f, 15–27.ix.2014, [#H4], leg. Japoshvili & Kirkitadze; 1f, 15–25.vi.2014; 1f, 25.vi.–5.vii.2014; 2ff, 5–15.vii.2014; 3ff, 15–25.vii.2014; 1f, 25.vii.–5.viii.2014; 1f, 5–15.VIII.2014; 1f, 25.viii.–4.ix.2014; 3ff, 4–14.ix.2014; 5ff, 15–27.ix.2014, 1f, 27.ix.–6.x.2014, [#H5], leg. Japoshvili & Kirkitadze; 3ff, 15–25.v.2014; 1f, 15–25.vi.2014; 2ff, 25.vi.–5.vii.2014; 9ff, 5–15.vii.2014; 1f, 25.vii.–5.viii.2014; 1f, 5–15.viii.2014, [#H6], leg. Japoshvili & Kirkitadze; 2ff, 25.v.–4.vi.2014; 1f, 15–25.vi.2014; 15ff, 25.vi.–5.vii.2014; 3ff, 1m, 25.vii.–5.viii.2014; 8ff, 1m, 5–15.viii.2014; 3ff, 1m, 15–25.viii.2014; 1f, 27.ix.–6.x.2014, [#H7], leg. Japoshvili & Kirkitadze.

##### 2. *Aphelinus asychis* Walker, 1839

**Material examined:** 1m, 15–25.vii.2014, [#H5], leg. Japoshvili & Kirkitadze; 1f, 5–15.vii.2014, [#H6], leg. Japoshvili & Kirkitadze.

##### 3. *Aphelinus chaonia* Walker, 1839

**Material examined:** 2ff, 4–14.vi.2014; 1f, 4–14.ix.2014, [#H1], leg. Japoshvili & Kirkitadze; 1f, 24.v.–4.vi.2014; 1f, 4–14.vi.2014; 1f, 15–25.vi.2014; 1f, 25.vi.–5.vii.2014, [#H3], leg. Japoshvili & Kirkitadze; 1f, 25.vi.–5.vii.2014, 1f, 5–15.vii.2014, [#H5], leg. Japoshvili & Kirkitadze; 1f, 4–14.vi.2014, [#H6], leg. Japoshvili & Kirkitadze; 3ff, 25.vi.–5.vii.2014, [#H7], leg. Japoshvili & Kirkitadze.

##### 4. *Aphelinus humilis* Mercet, 1927\*

**Diagnosis:** Body black or with the gaster mainly yellow to pale brown, head at least partly yellow. Scape almost 5.8 times as long as wide. Hind ocelli large, separated by not more than 0.5× their own major diameter from the orbits of eyes. Antenna with third funicular segment slightly longer than broad, F2 almost subequal to F1. Fore wings

with 1–6 hairs on the basal vein and with 1 or 2 lines of long hairs anterior to linea calva; costal cell slightly longer than marginal vein, and ventral surface with two complete row of hairs.

**Material examined:** 1f, 25.vii.–5.viii.2014, [#H5], leg. G. Japoshvili.

**Distribution:** Argentina, Belarus, Chile, Czech Republic, India, Georgia\*, Moldova, Netherlands, Portugal, Slovakia, Spain, Sweden, Ukraine, United Kingdom (Noyes, 2017).

**Hosts:** *Brachycaudus helichrysi*, *Brachycaudus spiraeae*, *Hyalopterus pruni*, *Macrosiphum* sp., *Myzus ligustri*, *Protaphis* sp. (Hemiptera: Aphididae) (Noyes, 2017).

**5. *Aphelinus kurdjumovi* Mercet, 1930**

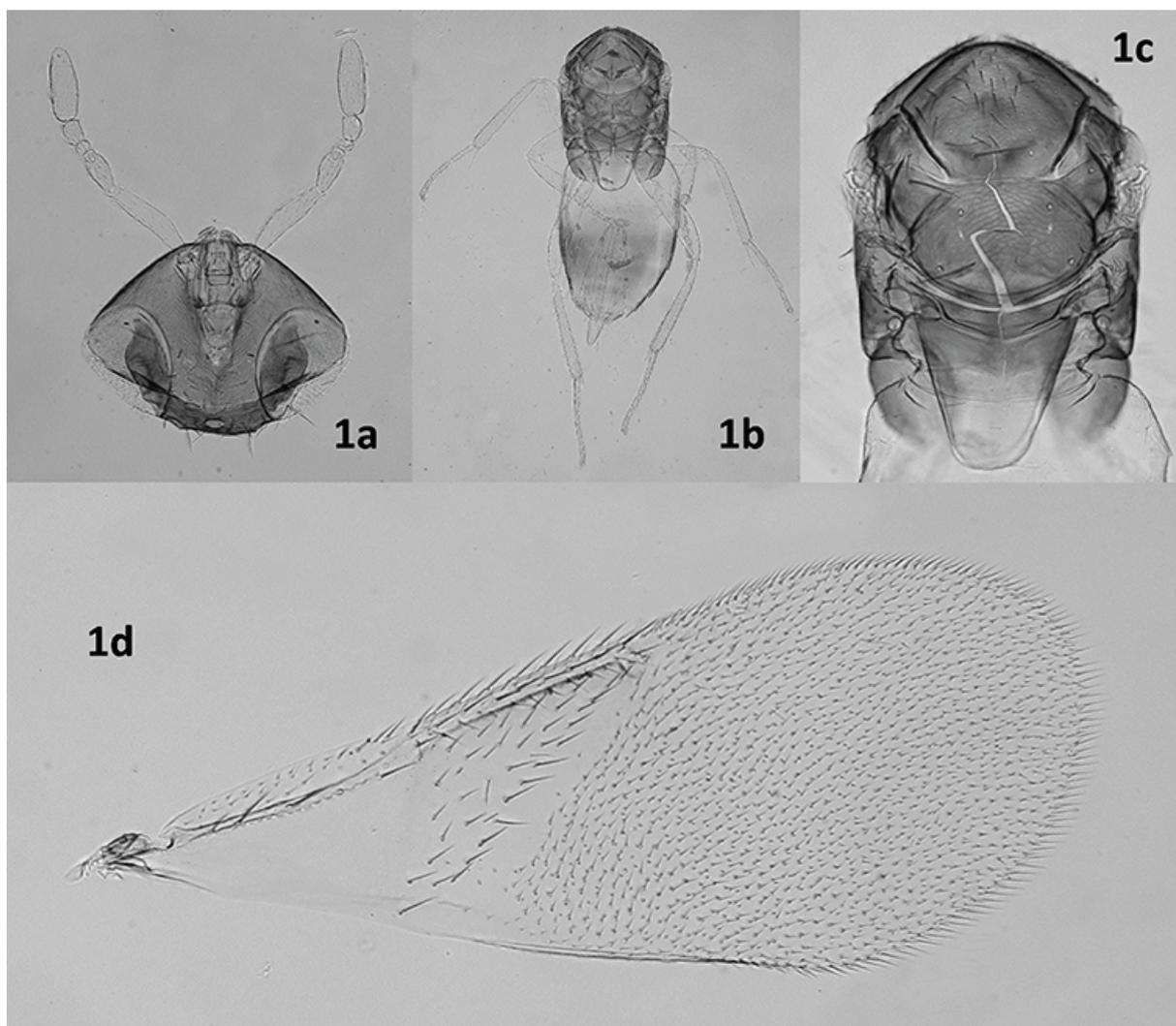
**Material examined:** 2ff, 5–15.vii.2014, [#H2], leg. Japoshvili & Kirkitadze; 2ff, 15–25.vii.2014, [#H3], leg. Japoshvili & Kirkitadze; 1f, 15–25.vi.2014; 1m, 27.ix.–6.x.2014, [#H4], leg. Japoshvili & Kirkitadze; 1f, 4–14.

vi.2014; 1f, 1m, 15–27.ix.2014, [#H5], leg. Japoshvili & Kirkitadze; 1f, 15–25.vi.2014; 1f, 15–25.vii.2014; 2ff, 25.vii.–5.viii.2014; 1f, 5–15.viii.2014, [#H6], leg. Japoshvili & Kirkitadze; 4ff, 25.vii.–5.viii.2014; 6ff, 5–15.viii.2014; 6ff, 15–25.viii.2014; 2ff, 25.viii.–4.ix.2014, [#H7], leg. Japoshvili & Kirkitadze.

**6. *Aphelinus lagodekhiensis* sp. nov.** (Figures 1a–1d)

**Description.** Female. *Body length.* 0.8–0.88 mm (holotype 0.88 mm) (CPD).

**Head.** Head 1.2× as broad as high in frontal view, about as broad as mesosoma; frontovertex width 0.4× of head width, 0.8× as long as broad, and 1.2× as broad as scape length; posterior ocelli 1.0× their diameter from eye margin, 4× their diameter from one another, 2× from anterior ocelli, and 1.0× their diameter from occipital margin; mandible with 2 acute teeth and a broad truncate surface below teeth, antenna as in Figure 1a, with scape



**Figure 1.** *Aphelinus lagodekhiensis* sp. nov.: a, ♀ head and antenna; b, ♀ body; c, ♀ thorax; d, ♀ forewing.

4× as long as broad, pedicel 2× as long as broad, F1 very small and subquadrate, F2 1.25× as broad as long, F3 1.3× as long as broad, club 2.9× as long as broad, 3.25× times as long as F3, and with 6 longitudinal sensilla. Antennal torulus separated from mouth margin by about its own length.

*Mesosoma* (Figures 1b and 1c). Mesoscutum and scutellum with fine reticulate sculpture, longest diameter of reticulations approximately twice diameter of scutellar sensilla, interior of reticulations with fine, granulate surface (visible only in slide mounts under high magnification); midlobe of mesoscutum with 2 pairs of long setae and about 45 short setae, side lobes each with 3 setae; scutellum with 2 pairs of long setae and two sensilla directly posterior to anterior pair of setae, scutellar sensilla slightly posterior to middle of scutellum; mesoscutum with short dark setae and a pair of long setae along posterior margin, scutellum with two pair of long setae; mesotibial spur 0.9× mesobasitarsus; metatibial spur 0.47× metabasitarsus.

*Fore wing* (Figure 1d). 2.5× as long as broad; costal cell with 1 complete row of dorsal setae and 2 rows of ventral setae, posterior row extending from under proximal end of marginal vein almost to stigma, costal cell 1.1× longer than marginal vein; submarginal vein with 5 or 6 setae; marginal vein with 8 or 9 setae along margin; stigma vein short with stigma rounded; delta region proximal to linea calva with two complete lines of 11 and 15 setae or so respectively and 10 additional setae in angle with marginal vein; wing distal to linea calva with dense, evenly spaced, dorsal setae and much smaller ventral setae.

*Hind wing*. 4.3× as long as broad, marginal fringe 0.33× wing width.

*Metasoma*. 1.3× as long as mesosoma; ovipositor inserted a little before middle of metasoma, slightly exerted distally, 1.2× and 1.3× as long as meso- and metatibiae respectively; third valvula almost one-fourth length of ovipositor.

*Color*. Head completely dark brown; antenna yellow. Mesosoma dark brown with metallic reflection. Tegula dark but not as dark as thorax. Gaster basal 2/5 yellow and rest brown. Legs yellow, only mid and hind coxae brown; hind tibia and fore wing with very slight infuscation.

**Comment:** The new species is most closely related to *A. flaviventris*, but differs in having the following morphological characters: mid coxae brown and F3 longer than broad, whereas in *flaviventris* the mid coxae is yellow and F3 subquadrate.

**Material examined:** HOLOTYPE: f, 15–27.ix.2014, [#5]; PARATYPE: f, 25.vi.–5.vii.2014, [#5] leg. G. Japoshvili (Slide mounted).

**Male:** Unknown.

**Host:** Unknown.

**Etymology:** The species is named for the Lagodekhi Reserve.

#### 7. *Aphelinus mali* (Haldeman, 1851)

**Material examined:** 1f, 24.v.–4.vi.2014, [#H1], leg. Japoshvili & Kirkitadze; 1f, 5–15.vii.2014, [#3]; 1f, 4–14.vi.2014, [#H4], leg. Japoshvili & Kirkitadze.

#### 8. *Aphelinus* sp.

**Material examined:** 1f, 15–25.vi.2014, [#H6], leg. Japoshvili & Kirkitadze.

**Comment:** This specimen of *Aphelinus* sp. has a wholly yellow body and dark hind tibia, but as the head is missing, it could not be described. Thus, this sample differs from all known species of *Aphelinus*, but additional material is needed for a proper description.

#### 9. *Aphelinus subflavescens* (Westwood, 1837)

**Material examined:** 1f, 23.iv.–4.v.2014; 2ff, 15–24.v.2014; 3ff, 24.v.–4.vi.2014; 2ff, 4–14.vi.2014; 2ff 15–25.vi.2014, [#H1], leg. Japoshvili & Kirkitadze; 1f, 24.v.–4.vi.2014, [#H2], leg. Japoshvili & Kirkitadze; 1f, 15–24.v.2014; 5ff, 1m, 24.v.–4.vi.2014; 2ff, 4–14.vi.2014; 1f, 25.vi.–5.vii.2014; 1f, 5–15.vii.2014; 1f, 27.ix.–6.x.2014, [#H3], leg. Japoshvili & Kirkitadze; 1f, 4–14.vi.2014; 1f, 25.vi.–5.vii.2014; 1f, 25.viii.–4.ix.2014; 1f, 15–27.ix.2014, [#H4], leg. Japoshvili & Kirkitadze; 1f, 4–14.vi.2014; 1f, 25.viii.–4.ix.2014; 1f, 27.ix.–6.x.2014, [#H5], leg. Japoshvili & Kirkitadze; 1m, 25.v.–5.vi.2014, [#H6], leg. Japoshvili & Kirkitadze; 1f, 25.vi.–5.vii.2014, [#H7], leg. Japoshvili & Kirkitadze.

#### 10. *Aphelinus sugonjaevi* sp. nov. (Figures 2a–2d)

**Description.** Female. *Body length*. 0.7–0.8 mm (holotype 0.8 mm) (CPD).

*Head*. Head 1.5× as broad as high in frontal view, about 1.2× as broad as mesosoma; frontovertex width 0.4× of head width, 0.8× as long as broad, and 1.25× as broad as scape length (Figures 2a and 2b); posterior ocelli 0.5× their diameter from eye margin, 3× their diameter from one another, 2× from anterior ocelli and 0.5× their diameter from occipital margin; mandible with 2 acute teeth and a broad truncate surface below teeth, antenna with scape 4.5× as long as broad, pedicel 1.4× as long as broad, F1 1.1–1.3× as long as broad, F2 1.2–1.5× as long as broad, F3 about 1.1× as long as broad, club 2.3–2.6× as long as broad, 2.2–2.6× times as long as F3, and with 4–5 longitudinal sensilla. Antennal torulus separated from mouth margin by about its own length.

*Mesosoma* (Figure 2c). Mesoscutum and scutellum with fine reticulate sculpture, longest diameter of reticulations approximately twice diameter of scutellar sensilla, interior of reticulations with fine, granulate surface (visible only in slide mounts under high magnification); mesoscutum with short dark setae and a pair of long setae at the apex, scutellum with two pairs of long setae; midlobe of

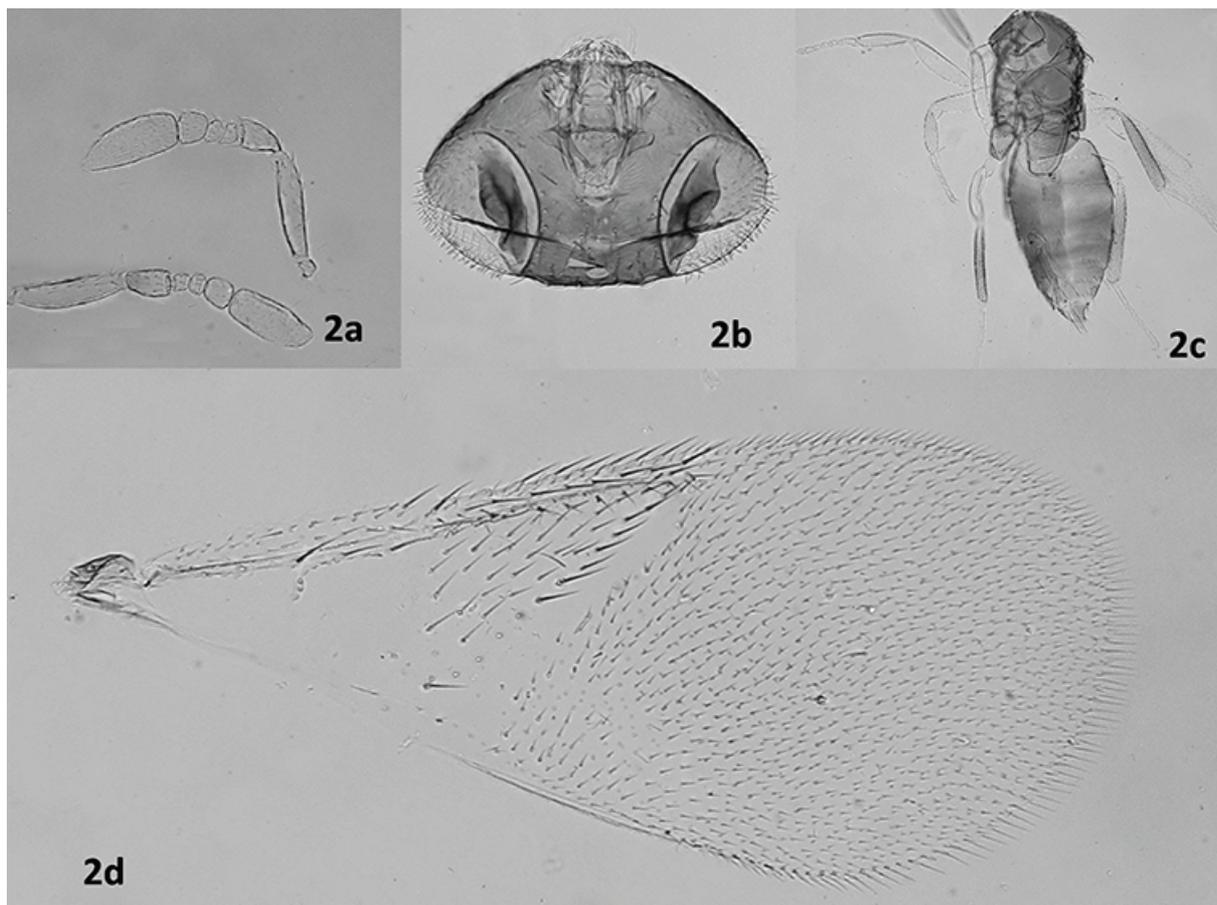


Figure 2. *Aphelinus sugonjaevi* sp. nov.: a, ♀ antenna; b, ♀ head; c, ♀ body; d, ♀ forewing.

mesoscutum with 2 pairs of long setae and about 55 short setae, side lobes each with 4 setae; scutellum with 2 pairs of long setae and two sensilla directly posterior to anterior pair of setae, scutellar sensilla in middle of scutellum; mesotibial spur 1× mesobasitarsus; metatibial spur 0.47× metabasitarsus.

*Fore wing* (Figure 2d). 2.4× as long as broad; costal cell with 1 complete row of dorsal setae and 2 rows of ventral setae, posterior row extending from under proximal end of marginal vein almost to stigma, costal cell 1.1× longer than marginal vein; submarginal vein with 5 or 6 setae; marginal vein with 9 or 10 setae along margin; stigma vein short with stigma rounded; delta region proximal to linea calva with one complete line of 14 setae and a second line going down more than half way, with 8 setae or  $\pm 1$ , and 18 additional setae in angle with marginal vein; wing distal to linea calva with dense, evenly spaced, dorsal setae and much smaller ventral setae.

*Hind wing*. 4.4× as long as broad, marginal fringe 0.29× wing width.

*Metasoma*. Metasoma about 1.1× as long as mesosoma; ovipositor inserted in middle of metasoma, slightly exerted distally, 1.1× and 1.3× as long as meso- and metatibiae respectively; third valvula almost one-fourth length of ovipositor.

*Color*. Head completely dark brown; antenna slightly infuscated or yellow. Thorax dark brown with metallic reflection. Tegula dark but not as dark as thorax. Gaster basal brown. Legs yellow, only mid and hind tibia and mid and hind coxae brown; fore tibia and fore wing with very slight infuscation.

**Comment:** The new species is most closely related to *A. brunneus*, but differs in having the following morphological characters: antennae yellow or infuscated,  $F1 = F2$  and anterior to linea calva with more than 45 setae, whereas in *A. brunneus* the antennae is brown,  $F2 > F1$ , anterior to linea calvae with fewer than 40 setae. The new species is also close to *A. lagodekhiensis* sp. nov. described above, but differs as follows:  $F3$  longer than broad, ovipositor 1.23 as long as mid tibia, mid tibia 8.6× as long as broad, whereas

in *A. lagodekhiensis*, F3 is subquadrate, the ovipositor is 1.28× as long as mid tibia, mid tibia 7× as long as broad, and there are more than 45 setae anterior to the linea calvae.

**Material examined:** HOLOTYPE: 1f, 15–25.vii.2014, [#H3], leg. G. Japoshvili (card-mounted); PARATYPES: 1f, 25.vi.–5.vii.2014, 1f, 5–15.viii.2014, 1f, 15–25.viii.2014, [#H7], leg. G. Japoshvili (card-mounted). 2ff, 15–25.viii.2014, [#H6], leg. Japoshvili & Kirkitadze; 2ff, 25.viii.–4.ix.2014, [#H7], leg. G. Japoshvili (1 card- and 1 slide-mounted).

**Etymology:** The species is named after Dr Eugeny Sugonjaev, for his great contribution in the study of taxonomy and ecology of chalcid wasps (Hymenoptera: Chalcidoidea) and their use in biocontrol.

#### 11. *Aphelinus thomsoni* Graham, 1976\*

**Diagnosis:** Body wholly yellow with only eyes and ocelli darker. Antennae and legs also yellow except tips of tarsi. Hind ocelli very small, separated by more than their own major diameter from orbits of eyes. Antenna with scape almost 6 times as long as broad; F3 slightly longer than broad, F2 slightly longer than F1. Forewing with 1–6 hairs on the basal vein and with 3 or 4 lines of long hairs anterior to linea calva; costal cell almost as long as marginal vein, and on ventral surface with two complete row of hairs. Ovipositor 0.5–0.7× as long as midtibia.

**Material examined:** 2ff, 2–12.iv.2014; 1f, 12–23.iv.2014, [#H1], leg. Japoshvili & Kirkitadze; Georgia, Lagodekhi Reserve, 1f, 4–14.vi.2014; 8f, 15–25.vi.2014, 7ff, 5m; 25.vi.–5.vii.2014, 1f, 1m; 5–15.vii.2014, [#H5]; 1f, 25.v.–4.vi.2014, [#H6], leg. Japoshvili & Kirkitadze; 4ff, 1m, 5–15.vii.2014; 4ff, 25.v.–4.vi.2014; 1f, 25.vi.–5.vii.2014, [#H7], G. Japoshvili.

**Distribution:** Czech Republic, **Georgia\***, Moldova, Russia, Slovakia, Sweden, Ukraine, United Kingdom (Noyes, 2017).

**Hosts:** *Drepanosiphum gracilis*, *Drepanosiphum platanoidis*, *Myzocallis annulata*.

#### 12. *Aphelinus varipes* (Forster, 1841)

**Material examined:** 1m, 25.vi.–5.vii.2014, [#H5], leg. Japoshvili & Kirkitadze.

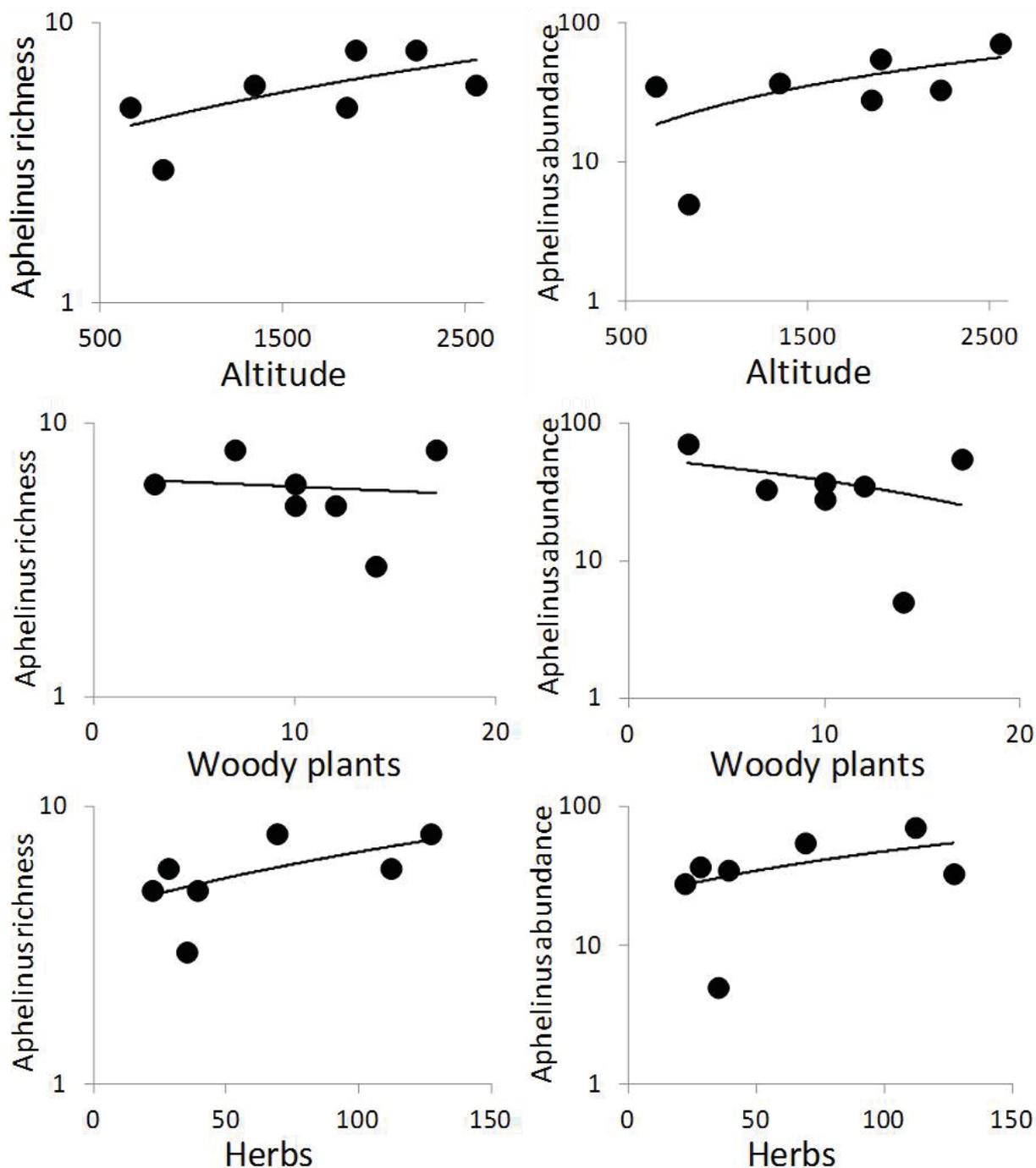
### 3.2. Spatial and temporal diversity patterns of *Aphelinus* in the LR

Rarefaction analyses (Gotelli and Colwell, 2001; Chao et al., 2016), based on the combined abundance data for all elevations and periods, produced an asymptotic curve, indicating the existence of only a single additional species after the doubling of sampling effort (not shown). This is not the case when each elevation is considered separately, where, on average, 2 additional species are expected. However, the incompleteness of the data is more

pronounced at higher elevations. Indeed, three species, recorded as singletons in pooled data (*A. humilis*, *A. lagodekhiensis* **sp. nov.**, and *A. sp.*), occurred only at the tree line (2000–2200 m), suggesting that more range-restricted species might occur at higher altitudes. On the other hand, species richness at the various elevations was not related with total abundance ( $R^2 = 0.38$ ,  $P < 0.05$ ). Therefore, the list of *Aphelinus* species in the LR can be considered as complete, but the exact elevational distribution of each species separately is incomplete. Indeed, very widespread species, such as *A. thomsoni* and *A. chaonia* (Noyes, 2017), are missing in H2 and H3, presumably as a result of undersampling rather than habitat-related absence.

The most abundant species (49% of total catch) at all elevations was *A. abdominalis*, which maintained its dominant position on both the spatial and temporal scale. Two other wide-ranging abundant species are *A. kurdjumovi* and *A. subflavescens*. These have an inverse abundance distribution associated with elevation. In particular, the relative abundance of *A. kurdjumovi* steadily increased with elevation and it was most abundant in alpine meadows, whereas *A. subflavescens* was abundant at lower elevations but the populations decreased with increasing elevation. These three species represented 75% of total abundance; all other species were relatively rare and had scattered distributions.

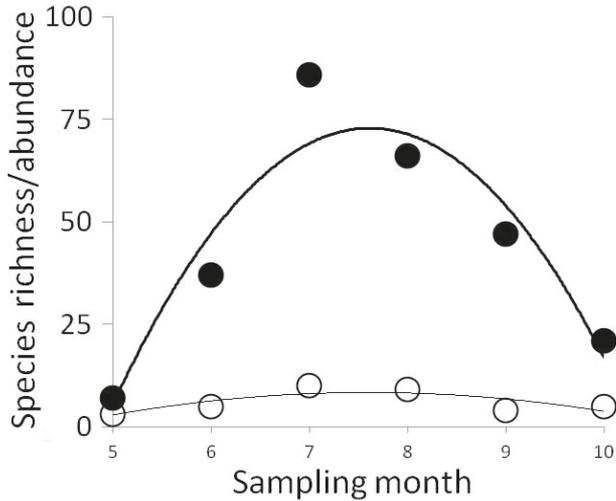
Taken as a whole, the data suggest that species richness, as well as total abundance, increased with increasing elevation with maximum diversity at the tree line (1900–2200 m). However, the trend is not statistically significant ( $P > 0.05$ ). A similar pattern was found with other parasitic hymenopterans along a similar gradient (Mumladze et al., 2017), while other animals showed a unimodal (Mumladze et al., 2017a) or decreasing (Aslan et al., 2017) pattern. Such inverse elevational patterns for parasitic Hymenoptera may be related to their host diversity. Although plant richness (which can be used as only a rough surrogate) does not significantly affect the richness or abundance of species of *Aphelinus*, the trends are still evident (Figure 3). In particular, increases in the richness of the herbaceous vegetation (as a result of increasing openness of forest canopy) is positively (though not significantly) correlated with the richness and total abundance of *Aphelinus* species. On the other hand, if we interpolate the species ranges (assuming that a species occurs everywhere between its elevational minima and maxima), then the species diversity takes a pronounced hump-shaped pattern peaking near the tree line (1800–2200 m). Although such range interpolation can be misleading (Hu et al., 2016), this result does generally agree with the raw data and hence can be accepted as valid.



**Figure 3.** The distribution of species richness and total density of *Aphelinus* in relation to elevation (OLS regression  $R^2 = 0.42$ ,  $P = 0.08$  and  $R^2 = 0.45$ ,  $P = 0.2$ , respectively), woody plant richness ( $R^2 = 0.01$ ,  $P = 0.6$  and  $R^2 = 0.18$ ,  $P = 0.6$ ), and herbaceous plant richness ( $R^2 = 0.41$ ,  $P = 0.1$  and  $R^2 = 0.29$ ,  $P = 0.2$ ).

Species richness as well as total abundance of *Aphelinus* is strongly structured temporally. At lower elevations, species richness and abundance are rather uniformly distributed across vegetation seasons, while species richness and total abundance peaked in July at higher

elevations. Because of this, the combined data for all elevations show a maximum diversity and abundance in July although not all the species were encountered at this time (Figure 4). This is similar to the findings of Hall et al. (2015), who showed that elevational patterns of species



**Figure 4.** Species abundance (black circles) and richness of *Aphelinus* along a temporal scale. Trend lines represent second-order OLS regressions (abundance  $R^2 = 0.83$ ,  $P < 0.01$ ; richness  $R^2 = 0.61$ ,  $P < 0.01$ ).

diversity of hymenopterans could be significantly different between the sampling occasions. Hence, comparisons between elevational diversity patterns in different geographical regions are further complicated in seasonal animal groups when the sampling period will not be adjusted appropriately (Ulrich, 2005; Timms et al., 2016).

To summarize, the diversity of *Aphelinus* species in the LR during 2014 increased with increasing altitude, up to subalpine-alpine areas (2200 m), and the species richness and total abundance of *Aphelinus* species attained a maximum in July. Although a single Malaise trap per elevation may not be the best sampling methodology, whole-year sampling even based on a single Malaise trap per elevation proved effective to capture total (gamma) species diversity of parasitic hymenopterans.

**3.3. Implications for large-scale biodiversity**

The Caucasus is a Plio-Pleistocene refugium that maintained relic diversity during the glaciations (Velichko and Kurenkova, 1990; Van Andel and Tzedakis, 1996). A number of taxa remained restricted to the region after deglaciations due to the impermeability of the great Caucasus mountain chains (Pokryszko et al., 2011) and hence the Caucasus played a minor role in developing recent communities in the further north. This caused a high regional endemicy and high dissimilarity of molluscan communities between the Caucasus and the adjacent northern regions or Europe (Sysoev and Schileyko, 2009; Pokryszko et al., 2011; Mumladze et al., 2014; Walther et al., 2014). In other taxa such as corticioid fungi (which are presumably better dispersers than mollusks), the Caucasus is assumed to play an important role in shaping the fungal

communities in the north and Europe (Ghobad-Nejhad et al., 2012). The significant role of the Caucasus in developing the flying insect communities of European or northern Palearctic regions as a whole is also apparent; e.g., Japoshvili et al. (2016) showed that the South Caucasus and particularly the LR harbors all 12 species of the genus *Tamarixia* (Hymenoptera, Eulophidae) that occur in Europe and suggested the Caucasus as a main colonization area for Europe. Eleven species (plus one morphospecies) of *Aphelinus* occurring only in the LR and 19 species in the South Caucasus (21% and 37% of total Palearctic fauna, respectively) also reinforce this view, assuming that these insects are rather poorly inventoried in the Caucasus. Recent studies indicate an existence of multiple refugia within the Caucasus region (Tarkhnishvili et al., 2012; Neiber and Hausdorf, 2015) that is presumably a reason for the high within-region dissimilarity of communities (Pokryszko et al., 2011). Such data are hardly available for insects, and we assume the existence of many more species of any insect taxon (particularly microhymenopterans) in the region, which, if true will definitely increase the resolution of current views. However, much more work is needed to gather comprehensive biodiversity data for the South Caucasus region in addition to molecular-genetic approaches.

**3.4. Key to females of *Aphelinus* species distributed in the Middle East and Caucasus**

1. Brachypterous: tip of forewing, not reaching apex of gaster ..... *asychis*  
 - Macropterous: tip of forewing reaching beyond apex of gaster ..... 2
2. Body entirely yellow ..... 3  
 - Body with dark parts ..... 6
3.  $F_3$  much shorter than  $F_1$ - $F_2$  combined length ..... 4  
 -  $F_3$  almost as long as  $F_1$  and  $F_2$  together ..... 5
4. All funicular segments almost equal .....  
 ..... *subflavescens*  
 -  $F_1$  and  $F_2$  almost subequal  $F_3$  at least a little longer than broad ..... *perpallidus*
5.  $F_3$  longer than broad ..... *thomsoni*  
 -  $F_3$  transverse ..... *flavus*
6. Costal cell of forewing without hairs or with only one complete row ..... 7  
 - Costal cell of forewing with two or three complete rows of hairs ..... 8
7. Hind ocelli separated by less than their own major diameter from the orbits of eyes; antenna with third funicular segment almost quadrate,  $F_2$  slightly longer than  $F_1$  ..... *abdominalis*  
 - Hind ocelli very small, separated by more than their own major diameter from the orbits of eyes; antenna with third funicular segment slightly longer than broad,  $F_2$  almost as long as  $F_1$  ..... *asychis*

8. Antennae and legs yellow, including fore and mid coxae and usually distal part of hind coxa ..... *flaviventris*  
 - Not all of antennae and legs yellow, at least mid and hind coxae brown ..... 9  
 9. All femora broadly, or mainly dark brown; setae less than 40 setae anterior to linea calva ..... *brunneus*  
 - At least hind femur entirely yellow ..... 10  
 10. Only hind femur entirely clear pale yellow ..... 11  
 - Fore tibia yellow or at most slightly infuscated ..... 12  
 11. Mid and hind tibia brown ..... *meridionalis*  
 - Mid and hind tibia yellow except apices and all tarsi yellow ..... *demyaati*  
 12. Fore tibia with dark part or at most slightly infuscated ..  
 ..... 13  
 - Fore tibia entirely yellow ..... 14  
 13. F<sub>3</sub> 1.2–1.5× as long as broad ..... *paramali*  
 - F<sub>3</sub> only slightly wider than long or equal ..... *gossypii*  
 14. Forewing with only one complete line, from basal part of wing until to linea calva; with second line extending at most half way down wing ..... *mali*  
 - Forewing with more numerous hairs in two or more lines, from basal part of wing until to linea calva and with second line extending at least three quarters of way down wing ..... 15  
 15. At least midfemora slightly infuscate medially ..... 16  
 - All femora entirely yellow ..... 17  
 16. Forewings, from basal part of wing until linea calva, with one complete and 2 or 3 incomplete lines of hairs .....  
 ..... *chaonia*  
 - Forewings, from basal part of wing until to linea calva, with 5 or 6 complete lines of hairs ..... *fusciscapus*  
 17. Hind tibia yellow ..... 18  
 - Hind tibia at least slightly infuscate ..... 20  
 18. Pedicel at most 2× as long as third funicular segment's length ..... 19  
 - Pedicel slightly less than 3× as long as third funicular segment and slightly longer than wide ..... *kurdjumovi*  
 19. F3 slightly wider than long; fore coxae fuscous .....  
 ..... *atriplicis*  
 - F3 longer than broad; fore coxae yellow .....  
 ..... *lagodekhiensis* sp.nov.  
 20. F1 and F2 together slightly less than half, as long as pedicel ..... *hordei*  
 - F1 and F2 together almost two-thirds as long as pedicel ..  
 ..... 21  
 21. Clava at least 3× as long as wide ..... *yasnoshae*  
 - Clava at most 2.6× as long as wide ..... 22  
 22. Marginal vein of forewings shorter than submarginal ...  
 ..... 23

- Marginal vein of forewings almost as long as or longer than submarginal ..... 24  
 23. Only hind tibia with very slight infuscation; FV on slide 0.4× as broad as head width ..... *babaneuri*  
 - Mid and hind tibia brown; FV on slide almost 0.33× as broad as head width ..... *sugonjaevi* **sp. nov.**  
 24. Head black, forewing with speculum closed below .....  
 ..... *varipes*  
 - Head with yellow part, forewing with speculum open below ..... *humilis*

#### 4. Conclusion

Two species of *Aphelinus* Dalman, 1820 (Hymenoptera: Aphelinidae), *A. humilis* Mercet and *A. thomsoni* Graham, are recorded for the first time from Georgia and the Caucasus, and two species (*A. lagodekhiensis* **sp. nov.** and *A. sugonjaevi* **sp. nov.**) are described as new to science. To facilitate species identification we have developed a key to the females of all 24 species of *Aphelinus* currently known from the Middle East and the Caucasus. As a result, the species number of *Aphelinus* is increased up to 19 for the Caucasus region, of which 18 are currently known from Georgia.

Both species richness and abundance of *Aphelinus* increased with increasing elevation although no statistically significant relationship was found. In total, 264 specimens belonging to 11 species (+1 morphospecies) of *Aphelinus* were collected in the LR during 2014.

Maximum diversity and abundance were observed in July, and this was more pronounced at higher elevations.

**Nomenclatural acts:** This work and the nomenclatural acts it contains have been registered in ZooBank. The ZooBank Life Science Identifier (LSID) for this publication is: <http://zoobank.org/urn:lsid:zoobank.org:pub:9C60B85C-2555-4DBD-8C2B-55EBAC5CF9C2>

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