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The genera *Anafroptilum* Kluge, 2011 and *Neocloeon* Traver, 1932, reinstated status, in North America, with remarks about the global composition of *Centroptilum* Eaton, 1869 (Ephemeroptera: Baetidae)

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Abstract

The mayfly genus *Centroptilum* Eaton, 1869, *s.s.*, (Ephemeroptera: Baetidae), as presently understood, is not known to occur in North America. Nearctic species recently classified there belong either to *Anafroptilum* Kluge, 2011 or to *Neocloeon* Traver, 1932, **reinstated genus**. The North American endemic *Neocloeon* differs fundamentally from *Anafroptilum* in that it possesses a patella-tibial suture on the foreleg of larvae and female adults, a characteristic that is shared with certain other baetid genera. *Neocloeon* includes the obligate parthenogen *N. triangulifer*, **new combination**, and a sexual species, *N. alamance*, **reinstated combination**. Nearctic *Anafroptilum* include: *A. album* (McDunnough, 1926), **new combination**, *A. asperatum* (Traver, 1935), **new combination**, *A. bifurcatum* (McDunnough, 1924), *A. conturbatum* (McDunnough, 1929), **new combination**, *A. minor* (McDunnough, 1926), **new combination**, *A. ozarkense* (Wiersema & Burian, 2000), **new combination**, *A. semirufum* (McDunnough, 1926), **new combination**, and *A. victoriae* (McDunnough, 1938), **new combination**. Further study will be required to determine the species composition of *Anafroptilum* and *Centroptilum*, *s.s.*, in the Palearctic and Oriental realms. *Anafroptilum* and *Neocloeon* are part of the *Cloeon* complex of genera, but *Centroptilum*, *s.s.*, is not.

Key words: long-clawed baetids, small minnow mayflies, *Centroptilum luteolum* (Müller, 1776), modified identification key, Anteropatellata

Introduction

The generic limits of the so-called long-clawed Baetidae (Ephemeroptera) are generally poorly known (Kjærstad *et al.* 2012), but recent advances are improving our understanding of this group of small minnow mayflies and helping us to recognize natural groupings. Kluge (2011), for example, recently described *Anafroptilum* Kluge, 2011, a new genus group for some Nearctic and east Palearctic species formerly classified in the genus *Centroptilum* Eaton, 1869. Kluge (2011) noted that *Centroptilum*, *s.s.*, is distinguished from *Anafroptilum* by having male adults with free gonovectes that are not fused with the penial bridge (compare Grandi 1960: Fig. XI-3 and Kluge 2011: Fig. 45), and by having larvae that do not possess the distinct rows of small but prominent spines along the lateral margins of the posterior abdominal segments VIII and IX (sometimes more). It should be noted that *Centroptilum luteolum* (Müller, 1776), the type species of *Centroptilum*, does possess acute processes that are considered to be some form of cuticle texturing or armature, but they are different from the lateral spines of *Anafroptilum*. The possession of these true lateral spines is one larval character used by Hill *et al.* (2010) to define the *Cloeon* complex of genera, which is nearly equivalent to Kluge & Novikova's (1992) concept of *Cloeon* Leach, 1815, *s.l.* Note that the type species of *Centroptilum* does not possess the defining characteristics of the *Cloeon* complex as elaborated here and further below, while *Anafroptilum* does possess these defining characteristics.

Kluge (2011) intuitively considered the presence of the patella-tibial suture (see, e.g., Kluge 2011: Fig. 39) on the forelegs of larvae and female adults to be a synapomorphy for the baetid genera grouped together in

Anteropatellata (see: Kluge 1997, 2004; Kluge & Novikova 2011), a characteristic that is lacking in *Anafroptilum*. Kluge (2011) formally transferred only one Nearctic *Centroptilum* species, *Centroptilum bifurcatum* McDunnough, 1924, to *Anafroptilum*, because that was the only species he was able to examine, but he indicated that the genus contained several other Nearctic species. In addition to *C. bifurcatum*, most recently there have been nine other Nearctic species included in *Centroptilum* (McCafferty & Waltz 1990, Lowen & Flannagan 1991, Wiersema & McCafferty 1998, Wiersema & McCafferty 2004, Funk *et al.* 2006), and we address each one below.

Since the synoptic work of McCafferty & Waltz (1990), the generic concept of *Centroptilum* has also included the North American genus *Neocloeon* Traver, 1932. *Neocloeon* had been considered at one time to be a synonym of *Cloeon* Leach, 1815 (Edmunds *et al.* 1976). *Neocloeon* was established for the species *Neocloeon alamance* Traver, 1932, which is the only species ever formally classified there. Herein, we re-evaluate the status and composition of *Neocloeon*, *Anafroptilum* and *Centroptilum* in light of Kluge's (2011) work and other recently available data and interpretations (e.g., Funk *et al.* 2006). We also address the diagnoses of those taxa present in North America.

Material and methods

We examined specimens representative of *Centroptilum luteolum*, *Anafroptilum bifurcatum* and the remaining nine Nearctic species that most recently have been classified in *Centroptilum*, including *C. alamance* (type species of *Neocloeon*). These specimens are housed in our personal collections (LMJ, NAW), Colorado State University, Fort Collins, Colorado, USA (CSU) and the Purdue University Entomological Research Collection, West Lafayette, Indiana, USA (PERC).

Results

We found that no Nearctic species match the strict type concept of *Centroptilum*, as detailed by Kluge (2011). We found that larvae of the following species most recently classified in *Centroptilum* possess distinct rows of small but prominent spines along the lateral margins of at least abdominal segments VIII and IX (although some may be reduced or obscure); larvae and female adults of these species lack the distinct patella-tibial suture on the foreleg; and male adults have gonovectes that are fused with the penial bridge, as in Kluge's (2011) figure 45. Therefore, the following species belong to *Anafroptilum*: *A. album* (McDunnough, 1926), **new combination**, *A. asperatum* (Traver, 1935), **new combination**, *A. bifurcatum* (McDunnough, 1924), *A. conturbatum* (McDunnough, 1929), **new combination**, *A. minor* (McDunnough, 1926), **new combination**, *A. ozarkense* (Wiersema & Burian, 2000), **new combination**, *A. semirufum* (McDunnough, 1926), **new combination**, and *A. victoriae* (McDunnough, 1938), **new combination**.

We found that two additional North American species recently classified in *Centroptilum* also have the defining characteristics of the *Cloeon* complex, but they possess a presumably apomorphic patella-tibial suture on the foreleg of larvae and female adults, which is shared by the so-called Anteropatellata and not *Anafroptilum*; these include *N. alamance* and *Cloeon triangulifer* McDunnough, 1931, which Funk *et al.* (2006) considered sister species. In order to recognize this hypothetical phylogenetic distinction, **reinstatement** of *Neocloeon* is proposed to include *N. alamance* Traver, 1932, **reinstated combination**, and *N. triangulifer* (McDunnough, 1931), **new combination**. Additional characteristics that distinguish *Neocloeon* from *Anafroptilum* in North America are discussed below.

Discussion

Wiersema and McCafferty (2004) revised the species taxonomy of three of the species now in *Anafroptilum*; none of the others have junior synonyms.

McCafferty *et al.* (2010) reported *Centroptilum* "sp. A" from Little Ivy Creek in Madison County, North Carolina, a species which has yet to be named and described formally, but it is a species that fits our concept of

Anafroptilum. An obligately parthenogenetic lineage of *A. minor* might represent an additional new species (Webb *et al.* 2012: Text S1: 14). McCafferty *et al.* (2012) indicated another possibly new species near *A. album* from Arizona, and McCafferty and Davis (1992) reported an unnamed species from Texas that Wiersema and McCafferty (1998) later considered to be a variant of *A. album*. In addition to these, we have seen several other potentially new species of *Anafroptilum* in North America.

We note here that the *A. minor* group is atypical of *Anafroptilum*, in that distinct dorsal body projections are present in the larval stage. The U.S.A. Mountain West species *A. asperatum* (see McCafferty *et al.* 2012 for distribution data and notes) has the lateral abdominal spines reduced to the extent that they are obscure or sometimes apparently absent; however, it is otherwise exactly like other, more typical Nearctic *Anafroptilum* species, and it has the middle of tergum IX expanded posteriorly and without spines, as do several other *Anafroptilum* species.

In addition to *N. alamance* and *N. triangulifer*, a third species of *Neocloeon* may be present in eastern North America; this taxon is morphologically indistinguishable from the parthenogenetic *N. triangulifer*, but it is identifiable via DNA barcodes and allozyme data. The unnamed species demonstrates further biological differences from the other two, including morning emergence of subimagos and winter egg diapause (Webb *et al.* 2012: Text S1: 10). Also worth remark here is that McCafferty and Davis (1992) reported a species with a unique abdominal color pattern that Wiersema and McCafferty (1998) subsequently considered to be a variant of *N. triangulifer*. This may represent a fourth species, but further investigation obviously is needed to test this hypothesis.

Funk *et al.* (2006) discussed the obligately parthenogenetic *N. triangulifer* and the sexual species *N. alamance*. We recommend re-evaluation of most historical records of these species, in light of Funk *et al.* (2006), as indicated by Myers *et al.* (2008), for example, for New York (Jacobus & McCafferty 2001). For a period of several years, the species *N. alamance* and *N. triangulifer* were treated as *de facto* synonyms by several Ephemeroptera specialists and others, resulting in the possibility of the two being identified or reported only as the latter species.

Further study of the Palearctic and Oriental species detailed below (all of which are unknown as larvae) is needed before a global understanding of *Centroptilum* and the *Cloeon* complex of genera, including also *Anafroptilum*, *Procloeon* Bengtsson, 1915 and others, can be reached. In the meantime, we maintain their generic attributions but consider their inclusion in *Centroptilum* doubtful.

Centroptilum campestre Gillies, 1949, *C. chinense* You & Gui, 1995 (note recent emendation to specific epithet by Bauernfeind & Soldán 2012), *C. henanensis* Zhou, Gui & Su, 1997, *C. rubidum* Kimmins, 1950 and *C. vitellinum* Ulmer, 1939 are known only in the male adult stage. *Centroptilum hungaricum* Pongrácz, 1913 and *C. rotundum* Takahashi, 1929 are known only in the female adult stage, the former species being based possibly on a teratological specimen (Keffermuller & Sowa 1984). *Centroptilum obtusum* Navás, 1915 is a dubious species from Spain based on alate material (Alba-Tercedor & Peters 1986; Bauernfeind & Soldán 2012). *Centroptilum lituratum* (Pictet, 1843) is based on alate material from Switzerland with the generic placement being highly questionable and its validity probably dubious at this time (Keffermuller & Sowa 1984, Bauernfeind & Soldán 2012). Additional Palearctic species very recently listed by Barber-James *et al.* (2013) as *Centroptilum* either have been reassigned to *Procloeon* or are subjective junior synonyms of other species (Bauernfeind & Soldán 2012).

The Australian species *C. collendum* Harker, 1957 and *C. elongatum* Suter, 1986 do not belong to *Centroptilum*, *s.s.*, and Webb & Suter (2011) indicated that they will be reassigned in the future. These species are very similar to the Neotropical genus *Callibaetoides* Cruz, Salles & Hamada, 2013 with respect to the armature of the crown of the maxilla, the shape of the labrum, the general leg shape, the setation of the glossae and paraglossae, and the lack of minute spines on the lateral margins of the abdomen (cf. Cruz *et al.* 2013).

Kluge (2011) noted that the only Old World species of *Centroptilum*, *s.s.*, is the type species, *C. luteolum*. Based on our examination of New World species and the resultant new combinations indicated above, we conclude that *Centroptilum* *s.s.* is not present in the Americas. Given the doubtful attribution of the majority of Eurasian species to *Centroptilum*, it is therefore possible that the concept of *Centroptilum* should be restricted to the type species. However, we note that the Eurasian species *C. pirinense* Ikonov, 1962 requires additional study (Bauernfeind & Soldán 2012).

Despite these global challenges, the various *Cloeon* complex genera are diagnosable in North America, and we will go so far as to hypothesize that the genus group *Neocloeon* is endemic to North America. The most recent larval key to North American mayfly genera by Waltz & Burian (2008) should be modified as follows to account

for the taxonomic changes herein. Hill *et al.* (2010) previously suggested changes to the Waltz & Burian (2008) key to accommodate the larva of *Waynokiops* Hill, Pfeiffer & Jacobus, 2010, another *Cloeon* complex genus. We deem it prudent to delay modifications of the adult key to North American *Cloeon* complex genera (Waltz & Burian 2008) until after the male adult of *Waynokiops dentatogriphus* Hill, Pfeiffer & Jacobus, 2010 is confirmed. However, we note that male adults of *Anafroptilum* and *Neocloeon* are distinguished from other Nearctic *Cloeon* complex genera by having a terminal forceps segment that is much longer than wide. *Neocloeon alamance* male adults are distinguished from *Anafroptilum* by having a distinct quadrate projection on the inner margin of the basal segment of the forceps (e.g., Traver 1935: Fig. 167; Traver 1935: Plate XL: Fig. 10).

Modification of Waltz & Burian's (2008) key to North American mayfly larvae, couplet 27

- 27(26'). Length of maxillary palp segment 3 subequal to segment 2 (Waltz & Burian 2008: Fig. 11.46); lateral bristles of caudal filaments present on proximal three-fourths, apices of filaments without bristles; gills simple; angulate mandible incisors usually deeply cleft to base or united less than one-half height of incisors (Waltz & Burian 2008: Fig. 11.45) 27a
- 27'. Length of maxillary palp segment 3, when present, shorter than segment 2 (Waltz & Burian 2008: Fig. 11.48); lateral bristles of caudal filaments present to apices; gills simple, or with dorsal flap at least on abdominal segment 1; angulate mandible incisors usually united above base or fused to apex (Waltz & Burian 2008: Fig. 11.47)*Procloeon* Bengtsson, 1915
- 27a (27'). Hindwingpads present*Anafroptilum*, in part
- 27a'. Hindwingpads absent 27b
- 27b (27a'). Abdominal segments with very few lateral spinules, usually restricted to posterolateral fourth of terga VIII and IX (rarely apparently absent); thoracic nota usually with variously developed dorsally projected bumps or spines; caudal filaments with subdistal band of darkened segments; middle sterna heavily darkened on anterior margin and with paired submedial dark dashes adjacent to the posterior margin; patella-tibial suture absent on foreleg*A. minor*
- 27b'. Abdominal segments III or IV to IX with many long, lateral spines; thoracic nota lack dorsal armature as above; caudal filaments with no subdistal band; middle sterna not marked as above; patella-tibial suture present on foreleg*Neocloeon*

Materials examined. *Anafroptilum album*. One larva, USA, Oregon, Benton Co., Corvallis, 25-iv-1997, NH Anderson, lab reared [PERC slide number 0,009,441]; one male adult, USA, Wisconsin, Adams Co., Carter Cr., 29-v-1976, emerged 1-vi, WL Hilsenhoff [PERC 0,009,480].

A. asperatum. One larva from long series of unknown number, USA, Oregon, Benton Co., intermittent stream, NW side Smith Hill 9 mi NW Corvallis, 1-iii-1970, M Tew [PERC]. Two female adults, one male adult, USA, Oregon, Benny Cr., 10 mi N Corvallis, temporary stream, 22-iv-1966 DM Lehmkuhl [PERC]. One reared female adult and associated larval exuviae from series, USA, Wyoming, Carbon Co., Medicine Bow NF, small trib to Deer Creek at Forest Rd. 101, 18-VII-1997, B. Kondratieff & R. Durfee [NAW].

A. bifurcatum. One larva, Canada, Alberta, Pembina R., 53/37N, 115/0W, 18-ix-1979, JC Ciborowski [PERC 0,009,443]. Five male adults, USA, Idaho, Cassia Co., Burley. 23-vii-1964, SL Jensen *et al.* [PERC 0,009,479].

A. conturbatum. Two larvae, Canada, Saskatchewan, Low Cr. at Hwy 904, 54/49/26N, 108/28/40W, 2000-vii-1, JM Webb [PERC]. Two male adults from series of unknown number, USA, Washington, Spokane Co., Dragoon Cr. near Deer Park, 4-viii-1962, GF Edmunds [PERC].

A. minor. One larva, Canada, Ontario, Algoma Dist., Avenge Tp., Little Carp R, 46/30.4N, 84/26.7W, 2-viii-1985 [PERC]. Unknown number male adults, USA, Alabama, Elmore Co., Sofkahatchee Creek 16-ix-1987, S. Harris [CSU]. Two male adults, USA, Alabama, Dekalb Co., W. fork of Little River at Desota St. Park, 22-vi-1988, KS Fraser [CSU]; One male adult, USA, Alabama, Clay Co., Cheaha Cr. at Forest rd. 637, 2.7 mi. W of Lake Chinnabee, 01-vi-1988, S. Harris [CSU]. Unknown number of larvae, USA, North Carolina, Randolph Co., Little Brushy Creek at SR 1005, 18-v-1990 [NAW]. Unknown number of larvae, USA, Texas, Waller Co., Ponds Creek at Hwy 290, 17-ix-1997, NA Wiersema [NAW]; unknown number of reared female adults and larvae, same data but 27-ix-1997 [NAW, PERC].

A. ozarkense. Five male adults (holotype and four paratypes), USA, Missouri, Shannon Co., Round Spring, 4-iii-1992, MA Blackwood [PERC]; One larva from long series, Oregon County, Eleven Point River, near Greenbriar Hollow, 15-VII-2000, R. Sarver [NAW].

A. semirufum. One larva, "Trout stream, Tracadis, NB, 4-viii-1950, R&E F" [PERC]. Two male adults from long series, USA, Montana, Madison, Burnt Tree Hole, 31-vii-1981 [PERC]. One male adult and associated larval exuviae, USA, Pennsylvania, Chester Co., White Clay Creek at Stroud Estate, 5-VI-1968 [NAW]; 38 larvae, east fork branch White Clay Creek at SWRC, 23-V-2005, D. Funk [NAW].

A. victoriae. Three larvae, USA, Montana, Chouteau Co., Eagle Cr., 16 mi SE Big Sandy, 48/03/26N, 109/48/

25W, 14-vi-2000, WP McCafferty *et al.* (MP465) [PERC]. One set larval exuviae from lab reared female, USA, Indiana, LaGrange Co., Pigeon Cr. at 1100 E, 10-vi-1974, L Dersch, D Tyler, (LD-3) (slide euparal xi-1984 RDW) [PERC]. One larva, USA, Michigan, Marquette Co., Lower Elm Creek .25 SW of Ives Lake Stone House, 9-11-vii-1985, WP McCafferty, AV Provonsha ["55-01 larva," PERC]; One larva, USA, Michigan, Marquette Co., Pine River at bridge on Compound Rd., Huron Mountain Association, 2-5-vi-1986, WP McCafferty (HM61-03) [PERC]. One male adult, USA, Maine, Somerset Co., Carrabassett River west of N. Anson rt-16, from oaks along road next to river, 13-vii-1986, SK Burian [NAW].

Two larvae from series of unknown number, USA, Vermont, Windhams Co., North Brook at W Edge of Wilmington, 20-vi-1976, WP McCafferty, AV Provonsha, M Minno [PERC].

Centroptilum luteolum. One larva, Ireland, 1973, no additional data [PERC].

C. pirinense. One larva, parts on slide, (det. RD Waltz, iii/1993), Turkey, 2-vii-1992, no additional data [PERC 0,009,483].

Neocloeon alamance. One larva in vial, one set male larval exuviae on slide, USA, Indiana, Putnam Co., Mill Cr., 4 mi S Manhatan, 27-vii-1978, AV Provonsha, D Bloodgood, P419, lab reared [PERC 0,009,435]. One male adult and two female adults, associated larval exuviae, USA, Indiana, Jefferson Co., Soluda Cr at Soluda, 16-vi-1977, AV Provonsha, M Minno, AA Alabi, Acc.2120 [PERC]. One set larval exuviae on slide, one male adult examined closely from long series reared specimens of unknown number, USA, Ohio, Lake Co., Kirtland, 2-ix-1942, JR Traver [PERC 0,009, 477].

N. triangulifer. Five female adults, USA, Pennsylvania, Chester Co., E Fk E Br White Clay Creek at Strout Water Research Center, 0.9 mi SW London Grove, 39/51/32N, 75/47/02W, Lab3, 28-v-1985 [PERC]; five larvae, one set exuviae, same locale, 13-viii-1985 [PERC], one larva on slide, same locale, clone #CT-H-18, reared by D Funk [PERC 0,009,474].

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