ASED http://e-ASED.org
Animal Systematics, Evolution and Diversity

Anim. Syst. Evol. Divers. Vol. 38, No. 2: 51-58, April 2022
https://doi.org/10.5635/ASED.2022.38.2.001

Four New Records of Monogonont Rotifers (Rotifera: Monogononta) from Korea

Hee-Min Yang, Gi-Sik Min*

Department of Biological Sciences and Bioengineering, Inha University, Incheon 22212, Korea

ABSTRACT

Four monogonont rotifers, *Filinia hofmanni* Koste, 1980, *Lecane pusilla* Harring, 1914, *Mikrocodides chlaena* (Gosse, 1886), and *Proales fallaciosa* Wulfert, 1937, were newly recorded in Korea. The genera *Mikrocodides* Bergendal, 1892 and *Proales* Gosse, 1886 were recorded for the first time in Korea. *Mikrocodides chlaena* and *Proales fallaciosa* were found from soil samples and are both soft-bodied species. *Filinia hofmanni* has previously been recorded mainly in Europe, and this is its first record in Asia. *Lecane pusilla* is the 24th lecanid rotifer recorded in Korea, and its morphological characteristics are consistent with previous research of *L. pusilla*. We have provided the morphological diagnoses of the four Korean specimens in this study, along with the partial sequences of mitochondrial cytochrome *c* oxidase subunit I (COI) gene of three species.

Keywords: *Filinia*, *Lecane*, *Mikrocodides*, Monogononta, *Proales*

INTRODUCTION

The monogonont rotifers in Korea have continuously been recorded by several researchers since the report by Hada in 1936 (Yamamoto, 1953; Turner, 1986; Song and Kim, 1989; Chung et al., 1991; Kim et al., 1993). To date, 323 rotifer species have been recorded in Korea, of which 200 are monogonont rotifers (National Institute of Biological Resources, 2021).

Among the monogonont rotifers recorded in Korea, there was a research bias for some specific taxa, especially for those with hard lorica or those which do not serious contraction or distorted due to fixative solutions, such as *Brachionus* Pallas, 1766, *Keratella* Bory de St. Vincent, 1822, *Lecane* Nitzsch, 1827, *Lepadella* Bory de St. Vincent, 1826, and *Trichocerca* Lamark, 1801. In addition, some genera, especially those with soft bodies, were rarely studied in Korea. For example, the family Dicranophoridae Harring, 1913 and Notommatidae Hudson & Gosse, 1886 contain 236 and 268 species, respectively (Jersabek and Leitner, 2013), but in Korea only 7 and 14 species, respectively, have been recorded.

Because of this research bias, we tried to find the monogonont rotifers that have not been studied much in Korea, especially the soft-bodied species. In Korea, the discovery of various taxa of monogonont rotifers is expected. The unique geographic and climatic characteristics of more than 60% of land is made up of mountains, land is surrounded by sea containing thousands of islands, and four distinct seasons with diverse climate patterns (Republic of Korea, 2014), create various habitats in Korea. Therefore, it is necessary to investigate various habitats by season to reveal the diversity of rotifers in Korea. In addition, since rotifers inhabit various habitat, it is necessary to apply various collection methods and tools.

In this study, we identified four monogonont rotifers that were newly recorded in Korea: *Filinia hofmanni* Koste, 1980; *Lecane pusilla* Harring, 1914; *Mikrocodides chlaena* (Gosse, 1886); and *Proales fallaciosa* Wulfert, 1937. This is the first record of the genera *Mikrocodides* Bergendal, 1892 and *Proales* Gosse, 1886 in Korea. *Mikrocodides chlaena* and *P. fallaciosa* are both soft-bodied species and considered to have a cosmopolitan distribution. In case of *F. hofmanni* and *L. pusilla*, this is the seventh and the 24th record of the respective genera from Korea. *Filinia hofmanni* has been considered a European species, and this is the first record of it in Asia. Here, we provide the diagnoses of the four Korean specimens and the partial mitochondrial cytochrome *c* oxidase subunit I (COI) sequences of three species.

*To whom correspondence should be addressed
Tel: 82-32-860-7692, Fax: 82-32-874-6737
E-mail: mingisik@inha.ac.kr

eISSN 2234-8190

MATERIALS AND METHODS

Of the four species, *F. hofmanni* and *L. pusilla* were collected from ponds using a 50 μm plankton net, while *M. chlaena*, and *P. fallaciosa* were collected and isolated from soil samples. The soil samples were air-dried in laboratory for a few weeks and rewetted using mineral water in a plant culture dish (SPL Life Science, Korea). The hatching rotifers were isolated into new plant culture dishes and cultured at room temperature.

For the morphological identification, we observed the rotifers under optical microscope (DM2500; Leica, Germany), and identified them based on the Koste and Voigt (1978), Koste and Shiel (1990a, 1990b), Segers (1995), Sanoamuang (2002), and Jersabek and Leitner (2013). Trophi preparation for scanning electric microscopy (SEM) was done following the method described by De Smet (1998). SU8010 and S-4200 (Hitachi, Japan) were used for SEM at 10–15 accelerating voltage. All examined specimens have been deposited in the National Institute of Biological Resources (NIBR).

DNA of three rotifer species were extracted using a LaboPass Tissue Genomic DNA Isolation Kit Mini (Cosmo Genetech, Korea) following the manufacturer's protocol. In case of *L. pusilla*, DNA could not be extracted because it was stored in a formalin-preserved sample. Polymerase chain reaction (PCR) was performed using two COI primers, LCO1490/HCO2198 (Folmer et al., 1994) and 30F/885R (Zhang et al., 2021). The PCR conditions for the Folmer primer were as follows: 95°C for 2 min for the initial denaturation; followed by 40 cycles at 95°C for 15 s, 42°C for 30 s, and 72°C for 1 min; and a final extension at 72°C for 5 min. The PCR conditions for 30F/885R were the same as that for the Folmer primer, except the annealing temperature of 51°C. PCR products were visualized by 1% agarose gel electrophoresis, and purified using LaboPass PCR Purification Kit (Cosmo Genetech). DNA sequencing was performed using PCR primers and ABI 3700 DNA Analyzer (Applied Biosystems, USA) at Macrogen, Korea.

The sequences were assembled and trimmed using Geneious 8.1.9 (https://www.geneious.com), and the intra-specific genetic variation were calculated using MEGA11 (Tamura et al., 2021).

SYSTEMATIC ACCOUNTS

[1*]Phylum Rotifera Cuvier, 1817
[2*]Class Eurotatoria De Ridder, 1957
[3*]Subclass Monogononta Plate, 1889
[4*]Order Flosculariaceae Harring, 1913
Family Trochosphaeridae Harring, 1913
[5*]Genus *Filinia* Bory de St. Vincent, 1824

[6*]*Filinia hofmanni* Koste, 1980 (Figs. 1B, 2A, B)

Filinia cf. *longiseta* Hofmann, 1979.
Filinia hofmanni: Koste, 1980: 240–245; Jersabek, 1996: 83; Sanoamuang, 2002: 244–245.

Material examined. Korea: 5 individuals, Incheon, Pond at Inha University, 37°27′00″N, 126°39′22″E, 19 Dec 2019.
Diagnosis. Body 130–160 μm in length, sac-shaped or oviform. Two lateral setae and one caudal seta present, lateral setae equal in length and inserted near corona. Lateral setae 260–300 μm, 2–3 times longer than body length. One movable caudal seta inserted ventrally. Caudal seta 137–170 μm in length. Distance from posterior end to caudal seta insertion is 15–25 μm. Two red eyes on head. Vitellarium with 14 nuclei. Trophi malleoramate type. Fulcrum straight, thin in dorso ventral view, broad and axe-shaped in lateral view. Rami inner margin with scleropili. Basal chamber of rami within thin wall structure, divide into the basal ramus chamber and the subbasal ramus chamber. Manubria crescent-shape, divided to three chambers. Unci located on the inner margin of manubria, containing 12/13 unci teeth.
Distribution. Austria, Belgium, Germany, Spain, Korea.
Remarks. *Filinia hofmanni* is similar to *F. longiseta* in morphological characteristics: sac-shaped body, movable caudal seta and the position of caudal seta insertion (Sanoamuang, 2002). The biggest difference between the two species is the number of teeth on unci. The number of unci teeth is a species-specific characteristic in the genus *Filinia* because it remains constant regardless of the environmental factors or the developmental stages (Sanoamuang, 1993). The European *F. hofmanni* have much fewer unci teeth than *F. longiseta*: 13–14/14–16 vs. 18–20/20–22 (Sanoamuang, 2002). The Korean specimen also has fewer teeth than *F. longiseta*: 12/13, which has one to three lesser number of teeth on each side than European *F. hofmanni*. The temperature of habitats was also different for *F. hofmanni* and *F. longiseta*. *Filinia longiseta* was recorded as warm-stenotherm (23–31°C), whereas *F. hofmanni* was recorded as cold-stenotherm (4–6°C) (Sanoamuang, 2002). The Korean specimen was also collected from cold water only (4–5°C).
Deposition. NIBRIV0000879590.
Molecular data. The partial COI sequences were obtained from four specimens. Intra-specific genetic distance was 0.0–1.4% (630 bp) (GenBank accession numbers: OM142482–OM142485).

Korean name: [1*]윤형동물문, [2*]진윤충강, [3*]단소아강, [4*]소화윤충목, [5*]삼지윤충속, [6*]호프만삼지윤충 (신칭)

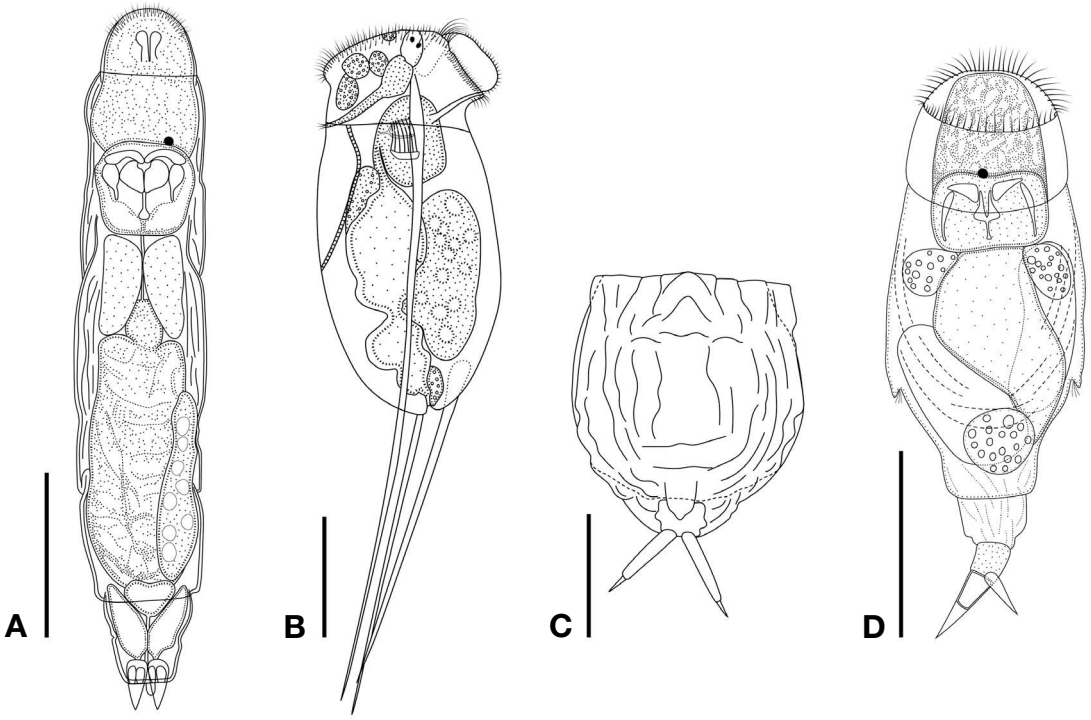

Fig. 1. Line drawing of rotifers. A, Dorsal view of *Proales fallaciosa*; B, Lateral view of *Filinia hofmanni*; C, Ventral view of *Lecane pusilla*; D, Dorsal view of *Mikrocodides chlaena*. Scale bars: A, B, D = 50 μm, C = 25 μm.

[1*]Order Ploima Hudson & Gosse, 1886
[2*]Family Lecanidae Remane, 1933
[3*]Genus *Lecane* Nitzsch, 1827

[4*]***Lecane pusilla*** **Harring, 1914 (Fig. 1C)**

Lecane pusilla: Harring, 1914: 541; Harring and Myers, 1926: 369; Kutikova, 1970: 449–450; Chengalath et al., 1973: 20; Koste and Voigt, 1978: 216; Koste and Shiel, 1990a: 31; Segers, 1995: 84.
Lecane nana Donner, 1954: 85–86.

Material examined. Korea: 3 individuals, Jeju-do, Pond in Seogwipo-si, 33°25′13″N, 126°50′42″E, 25 Jun 2021.
Diagnosis. Antero-lateral corner of lorica angulated. Dorsal plate anteriorly narrower than ventral plate. Anterior margin of dorsal plate flat. Middle of ventral plate narrower than dorsal plate. Length of dorsal plate is 50 μm, and that of ventral plate is 55 μm. Width of dorsal plate is 45 μm, and that of ventral plate is 42 μm. Both dorsal and ventral lorica ornamented, showing a pleated pattern. Posterior margin of foot plate round. Foot pseudosegment squircle shaped with a lateral extension in middle, not projecting from ventral plate. Toes short, 20 μm in length, and completely separated. Tips of toes bearing short claws, 4–5 μm in length.
Distribution. Cosmopolitan.
Remarks. *Lecane pusilla* has been recorded in all continents except the polar regions (Harring, 1914; Harring and Myers, 1926; Donner, 1954; Kutikova, 1970; Chengalath et al., 1973; De Smet, 1989; Koste and Shiel, 1990a; Sanoamuang et al., 1995). The morphological characteristics of *L. pusilla* can be confused with the following lecanid species: *L. aeganea* Harring, 1914, *L. doryssa* Harring, 1914, *L. inopinata* Harring & Myers, 1926, *L. sagula* Harring & Myers, 1926, *L. subtilis* Harring & Myers, 1926, and *L. undulata* Hauer, 1938, but can be distinguished by its small body size, completely separated toes, short claws, shape of foot pseudosegment, and the foot pseudosegment not projecting from ventral plate (Segers, 1995). The morphological characteristics of Korean *L. pusilla* are consistent with previous research.
Deposition. NIBRIV0000895314.

[5*]Family Epiphanidae Harring, 1913
[6*]Genus *Mikrocodides* Bergendal, 1892

[7*]***Mikrocodides chlaena*** **(Gosse, 1886) (Figs. 1D, 2E, F)**

Stephanops chlaena Hudson and Gosse, 1886: 76.

Korean name: [1*]유영목, [2*]술잔윤충과, [3*]술잔윤충속, [4*]작은술잔윤충(신칭), [5*]물윤충과, [6*]등주름윤충속(신칭), [7*]외발톱등주름윤충(신칭)

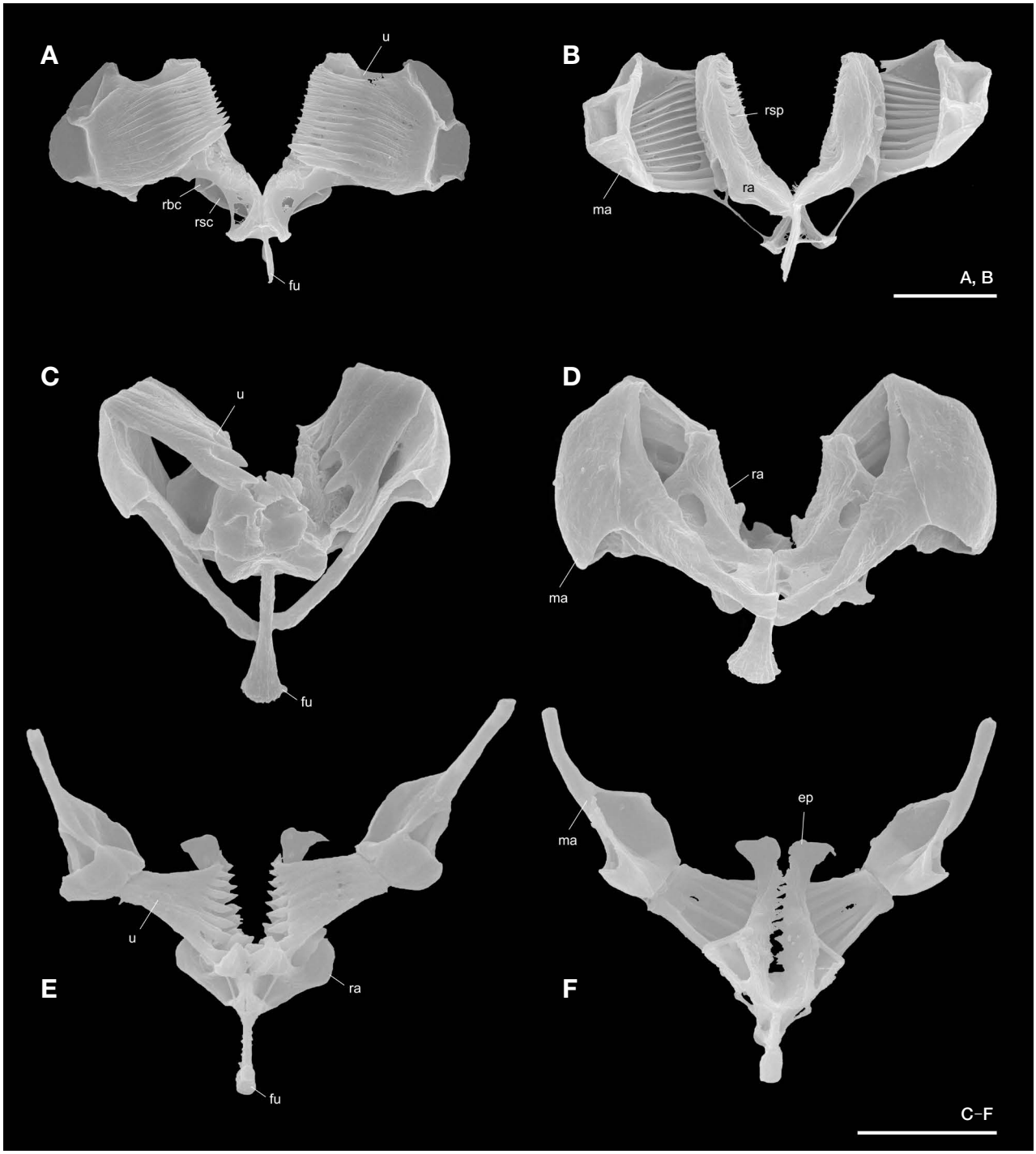

Fig. 2. Trophi observed by scanning electric microscopy. A, B, *Filinia hofmanni*; A, Ventral view; B, Dorsal view; C, D, *Proales fallaciosa*; C, Ventral view; D, Dorsal view; E, F, *Mikrocodides chlaena*; E, Ventral view; F, Dorsal view. ep, epipharynx; fu, fulcrum; ma, manubrium; ra, ramus; rbc, ramus basal chamber; rsc, ramus subbasal chamber; rsp, ramus scleropili; u, uncus. Scale bars: A–F = 10 μm.

Rhinops orbiculodiscus Thrope, 1891: 304.
Mikrocodides dubius Bergendal, 1892: 34.
Mikrocodides orbiculodiscus Jenning, 1894: 8.
Mikrocodides chlaena: Weber, 1898: 369; Wang, 1961: 108; Kutikova, 1970: 500; Koste and Voigt, 1978: 61; Koste and Shiel, 1987: 966; Jersabek, 2003: 62.

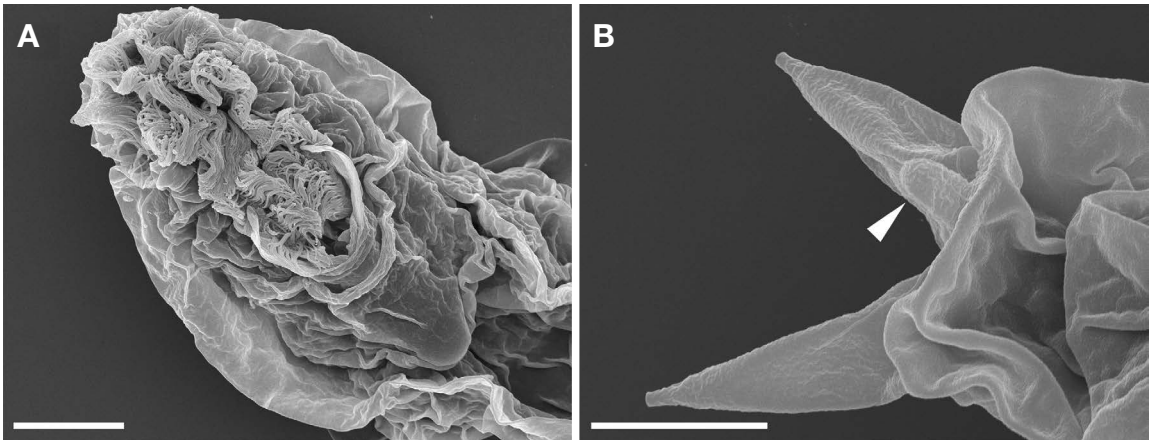

Fig. 3. *Proales fallaciosa* observed by scanning electric microscopy. A, Ventral view of corona; B, Toes and dorsal papilla (arrowhead). Scale bars: A=10 μm, B=5 μm.

Material examined. Korea: 5 individuals, Gyeongsangnam-do, Soil sample from Gimhae-si, 35°19′01″N, 128°48′10″E, 13 May 2020.

Diagnosis. Body flexible and illoricated, 150–160 μm in length. Corona short, located on the anterior margin of head. Head large, conspicuously divided from trunk. Trunk cylindrical, with lateral projections from two thirds of the trunk. Dorsal part of lorica with distinct longitudinal folds. Two toes completely separated. Toes of different lengths, 20 and 16 μm. Long toe pointed backwards and short toe pointed upwards. One red eyespot on brain. Trophi malleate, 17 μm in length. Fulcrum straight, with thick and blunt end. Rami rhomboid with several teeth on the inner margin. Upper part of rami connected to epipharynx. Unci with eight distinct teeth.

Distribution. Cosmopolitan.

Remarks. The genus *Mikrocodides* Bergendal, 1892 comprises of two species, *M. chlaena* and *M. hertha* Wulfert, 1961 (Jersabek and Leitner, 2013). *Mikrocodides chlaena* is easily distinguished from *M. hertha* based on the following characteristics: (1) toes asymmetrical and unique, (2) one cerebral eye, and (3) unci with eight teeth. In several studies on *M. chlaena* (Weber, 1898; Wang, 1961; Kutikova, 1970; Koste and Voigt, 1978; Koste and Shiel, 1987; Jersabek, 2003), the genus name was notated as '*Microcodides*'. We follow the genus name '*Mikrocodides*' based on the original description (Bergendal, 1892) and the standard list of names for use in taxonomy (Segers et al., 2012). Of the five genera of the family Epiphanidae Harring, 1913, two genera *Epiphanes* Ehrenberg, 1832 and *Rhinoglena* Ehrenberg, 1853 have been recorded previously from Korea (National Institute of Biological Resources, 2021), and this is the first record of the genus *Mikrocodides* in Korea.

Deposition. NIBRIV0000879591.

Molecular data. The partial COI sequences were obtained from three specimens, and the intra-specific distance was zero (663 bp) (GenBank accession numbers: OM142489–OM142491).

[1*]Family Proalidae Harring & Myers, 1924

[2*]Genus *Proales* Gosse, 1886

[3*]***Proales fallaciosa*** **Wulfert, 1937 (Figs. 1A, 2C, D, 3A, B)**

Proales decipiens Weber, 1898: 466.

Proales sordida Harring & Myers, 1922: 605.

Proales tyrphosa Bērziņš, 1948: 315.

Proales fallaciosa: Wulfert, 1937: 65; Wang, 1961: 159; Kutikova, 1970: 496; Koste and Voigt, 1978: 281; Koste and Shiel, 1990b: 135; De Smet, 1996: 70; Fontaneto and Melone, 2003: 258; Jersabek, 2010: 154.

Material examined. Korea: 5 individuals, Gyeongsangnam-do, Soil sample from Sancheong-gun, 35°27′54″N, 127°51′50″E, 19 Jan 2019.

Diagnosis. Body illoricated and flexible, 220–250 μm in length. Transparent and elongated cylindrically. Corona oblique. Trunk with pseudosegments and several longitudinal folds. Foot short, less than 1/8 of the total body length. Two pseudosegments on the foot. One small dorsal papilla located between two toes. Toes short, 7–8 μm in length. Tips of toes truncated. One red eyespot located behind the brain, slightly

Korean name: [1*]돌출윤충과, [2*]돌출윤충속 (신칭), [3*]작은돌기돌출윤충 (신칭)

right from the center in dorsal view. A pair of large and elongated gastric glands. Pedal glands subtriangular shape. Vitellarium with eight nuclei. Trophi virgate. Fulcrum extended straight with fan-shaped distal end. Length of fulcrum 8–9 μm. Inner margin of rami contains one blunt tooth on each side. Manubria broad at the anterior end, narrow and straight at the posterior end. Each uncus with five teeth with gradually decreasing sizes.

Distribution. Cosmopolitan.

Remarks. *Proales fallaciosa* is the first species of the genus *Proales* to be recorded in Korea. Previously, three species of the family Proalidae have been recorded in Korea, namely *Bryceella perpusilla* Wilts, Martinez Arbizu & Ahlrichs, 2010, *B. stylata* (Milne, 1886), and *Proalinopsis caudatus* (Collins, 1872) (see Song, 2015, 2017). The morphological characteristics of the Korean specimen corresponded to the previous studies except the number of unci teeth. De Smet (1996) recorded that the range of the unci teeth number was from 4 to 7, and Kutikova (1970) recorded that the Russian specimen had 6 teeth on the right uncus and 7 teeth on the left. The Australian specimen had been recorded to have 7 teeth on left and 5–6 teeth on right (Koste and Shiel, 1990b). The Korean specimen has 5 teeth on each side. Of the 48 species in the genus *Proales*, *P. fallaciosa* is the most similar to *P. gigantea* (Glascotte, 1893) and *P. ornata* Myers, 1933. However, *P. fallaciosa* is distinguished from the two species based on the following characteristics: (1) dorsal papilla of *P. fallaciosa* is simple and smaller than *P. gigantea*, (2) the length of two pseudosegments of foot is almost similar in *P. fallaciosa*, while that of the last segment of *P. ornata* is twice that of the penultimate segment, and (3) *P. ornata* has lateral protrusions beside the dorsal papilla, while *P. fallaciosa* has no lateral protrusions.

Deposition. NIBRIV0000879589.

Molecular data. The partial COI sequences were obtained from three specimens, and the intra-specific distance was zero (657–660 bp) (GenBank accession number: OM142486–OM142488).

ORCID

Hee-Min Yang: https://orcid.org/0000-0001-6288-1534
Gi-Sik Min: https://orcid.org/0000-0003-2739-3978

CONFLICTS OF INTEREST

Gi-Sik Min, a contributing editor of the Animal Systematics, Evolution and Diversity, was not involved in the editorial evaluation or decision to publish this article. Remaining author has declared no conflicts of interest.

ACKNOWLEDGMENTS

This work was supported by a grant from the National Institute of Biological Resources (NIBR), funded by the Ministry of Environment (MOE) of the Republic of Korea (NIBR 202002204).

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Received January 7, 2022
Revised March 28, 2022
Accepted March 29, 2022