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Brief description of 18 newly recorded ciliate species from soil and inland waters (Protozoa, Ciliophora) in South Korea

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Ciliates are a speciose protozoan group and their diversity is still not well investigated in Korea. From our field surveys, 18 unrecorded ciliate species were collected from a total of nine localities in Korea. The field surveys were conducted in 2018 and 2019, and the unrecorded ciliates were found from terrestrial (moss and soil samples) and inland water (river and lagoon samples) habitats. The morphology of these ciliates was studied using the observation of living and silver impregnated (protargol) specimens. The present species belong to five classes as follows: 1) class Spirotrichea - *Gonostomum kuehnelti*, *Quadristicha setigera*, *Lamtostyla decorata*, *L. islandica*, *L. longa*, *Anteholosticha brachysticha*, *Pseudobirojimia muscorum*; 2) class Litostomatea - *Apocoriplites lajacola*, *Epispathidium amphoriforme*, *Protospathidium muscicola*, *Phialinides australis*, *Paraenchelys wenzeli*, *Rimaleptus similis*; 3) class Nassophorea - *Drepanomonas revoluta*; 4) class Colpodea - *Bryometopus triquetrus*; and 5) class Oligohymenophorea - *Cyclidium glaucoma*, *Epistylis pygmaeum*, *Pseudovorticella vestita*. The globular macronuclear nodules of *P. vestita* were observed for the first time in the Korean population.

Keywords: Inland water, redescription, semiterrestrial, silver impregnation, taxonomy

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Introduction

Terrestrial and inland water habitats show an extraordinary high ciliate diversity suggesting that the majority of ciliate species are yet to be discovered (Foissner *et al*., 2002; 2008). For example, Foissner *et al*. (2002) identified 365 ciliate species, including newly established taxa only from the Namib Desert. Also, 459 terrestrial and semiterrestrial ciliate species were collected from Venezuela and the Galápagos (Foissner, 2016). Likewise, many species have been described from Korean terrestrial and inland water (Moon *et al*., 2017; Jung *et al*., 2017; 2018; 2019; Kim *et al*., 2019a; 2019b). In the present study, we discovered 16 species from terrestrial moss or soil, one from limnetic and one from brackish water. Also, a brief description, remarks, and photomicrographs are provided for each species.

Materials and Methods

The ciliate species were collected from terrestrial soil, mosses, freshwater, and brackish water in Korea. The collection locality and date are described in the 'Material examined' section of each species. The aquatic samples were collected and immediately transferred to the laboratory. The terrestrial samples were air dried for at least two weeks and rewetted using the non-flooded Petri dish method (Foissner *et al*., 2002). The raw cultures of aquatic samples were set up with two or three rice grains at room temperature (about 20°C).

Morphology was observed using a stereomicroscope (Olympus SZ11, Japan), an optical microscope (Olympus BX53, Japan) at low (×40−200) to high (×400−1000) magnifications, and captured using a digital camera (Olympus DP74, Japan). Protargol powder was synthesized using the method of Pan *et al*. (2013). The permanent samples were prepared using protargol impregnation method of the 'procedure A' (Foissner, 2014). The differential through-focal images of the protargol-impregnated specimens were merged using the software of Helicon Focus 6.8.0 (HeliconSoft Ltd, Ukraine). The terminology and classification follow Berger (2006; 2008;

2011) and Lynn (2008).

Results and Discussion

Phylum Ciliophora Doflein, 1901
Class Spirotrichea Bütschli, 1889
Subclass Stichotrichia Small & Lynn, 1985
Order Sporadotrichida Fauré-Fremiet, 1961
Family Gonostomatidae Small & Lynn, 1985
Genus *Gonostomum* Sterki, 1878

1. *Gonostomum kuehnelti* Foissner, 1987 (Fig. 1)

Material examined. Terrestrial moss collected from Mt. Odaesan, Odaesan-ro, Jinbu-myeon, Pyeongchang-gun, Gangwon-do, Korea (N 37°43′53.2″, E 128°35′23.4″) on 28 April 2018.

Diagnosis. Size in vivo 70−110 × 20−35 μm and 65−95 × 19−30 (n = 11) after protargol impregnation. Body ellipsoid to elongate ellipsoid with both ends narrowed and margins parallel. 15−23 macronuclear nodules usually arranged in two groups. Cortical granules rod-shaped, colorless, and 0.5 × 1 μm in vivo. Cytoplasm colorless. Adoral zone of membranelles about 45% of body length and composed of 25−29 membranelles. Three frontal cirri, single buccal cirrus, frontoventral row III with only one cirrus posterior to right frontal cirrus, frontoventral rows IV and V and frontoterminal row each consist of two cirri. Two pretransverse and two transverse cirri near cell end. Right and left marginal row composed of 22−26 and 16−19 cirri, respectively. Three dorsal kineties each ends with a single caudal cirrus.

Distribution. Antarctica, Austria, Germany, India, Italy, Kenya, Slovakia, Turkey, and Korea.

Remarks. *Gonostomum kuehnelti* is unique within the genus in having a higher number of macronuclear nodules arranged in two groups. The Korean population of *G. kuehnelti* fits the description of the type (Foissner, 1987), the Indian (Kamra *et al*., 2008), and the Chinese (Ning *et al*., 2019) population but differs mainly in the higher number of macronuclear nodules (15−23 vs. 10−17, 13−19, and 7−16, respectively).

Voucher slides. One slide with protargol-impregnated specimens were deposited at the Nakdonggang National Institute of Biological Resources (NNIBRPR11674).

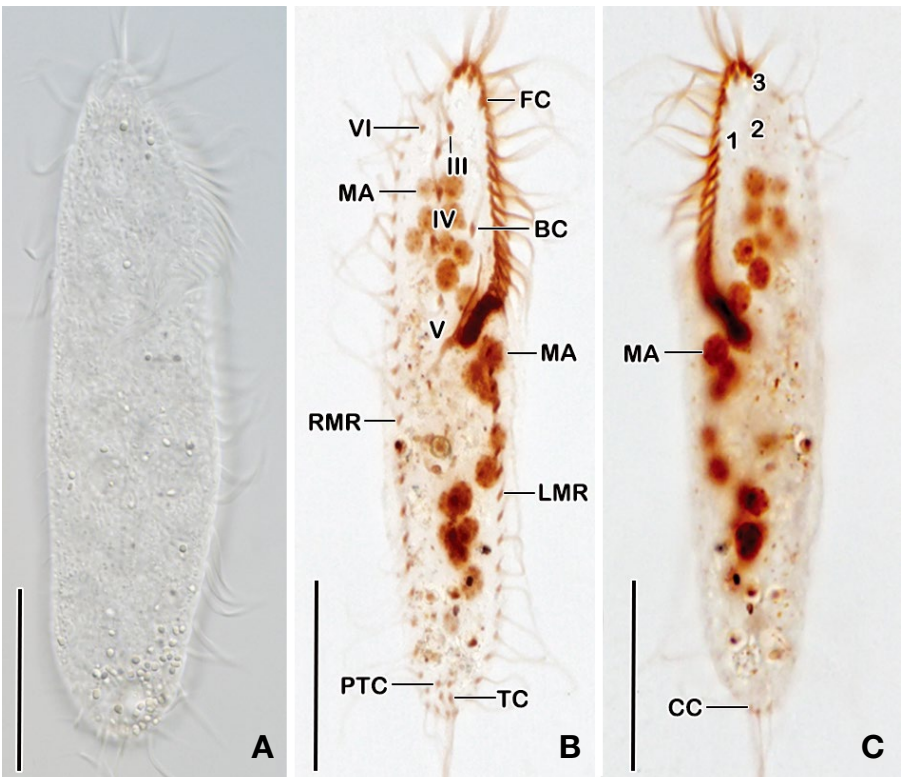

Fig. 1. *Gonostomum kuehnelti* from life (A) and after protargol impregnation (B, C). A. Ventral view of a representative specimen. B. Somatic and oral ciliature of ventral side. C. Dorsal kineties and nuclear apparatus. 1−3, dorsal kineties; III−VI, frontoventral rows; BC, buccal cirrus; CC, caudal cirri; FC, frontal cirri; LMR, left marginal row; MA, macronuclear nodules; RMR, right marginal row; PTC, pretransverse cirri; TC, transverse cirri. Scale bars = 30 μm.

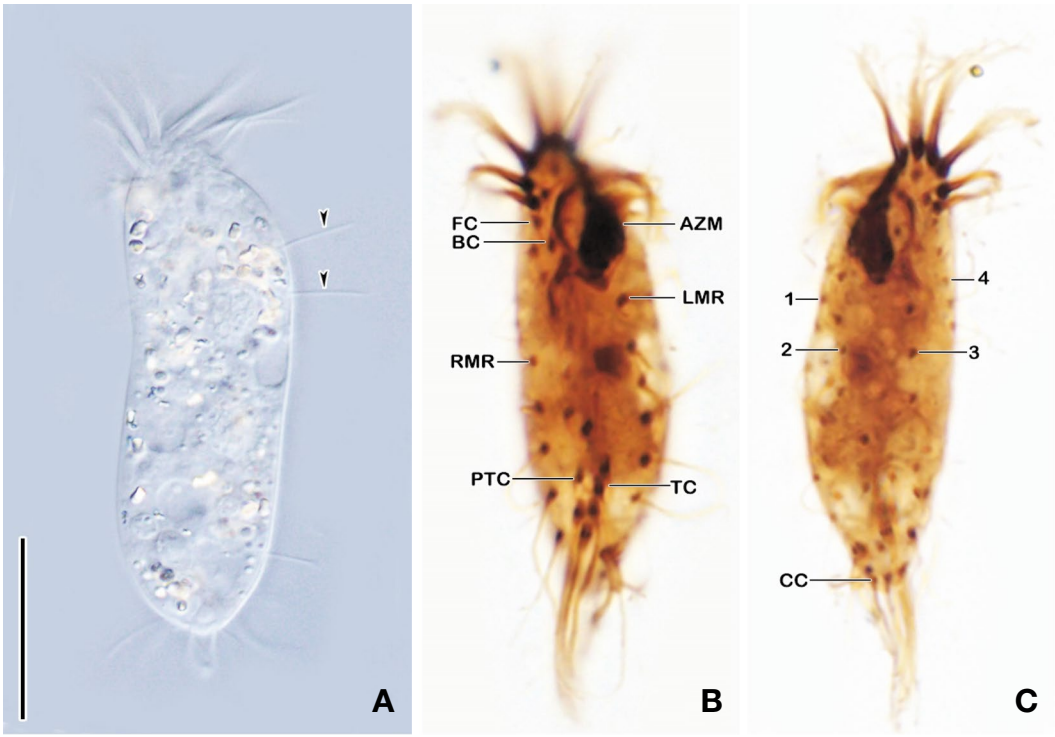

Fig. 2. *Quadristicha setigera* from life (A) and after protargol impregnation (B, C). A. Body outline in vivo and the long dorsal bristles (arrowheads). B. Somatic and oral ciliature of ventral side. C. Dorsal kineties. 1–4, dorsal kineties; AZM, adoral zone of membranelles; BC, buccal cirrus; CC, caudal cirri; FC, frontal cirri; LMR, left marginal row; PTC, pretransverse cirri; RMR, right marginal row; TC, transverse cirri. Scale bar = 20 μm.

Family Oxytrichidae Ehrenberg, 1830
Genus *Quadristicha* Foissner, 2016

2. *Quadristicha setigera* (Stokes, 1891) Foissner, 2016 (Fig. 2)

Material examined. Terrestrial moss collected from Mt. Yeonhwasan, Sinbun-ri, Yeonghyeon-myeon, Goseong-gun, Gyeongsangnam-do, Korea (N 35°04′08.2″, E 128° 13′47.1″) on 4 February 2019.
Diagnosis. Size in vivo 40–60 × 15–20 μm (n = 3). Two macronuclear nodules and a micronucleus in between. Cortical granules lacking. Adoral zone of membranelles about quarter of body size, consists of about 15 membranelles. Right marginal row commences at mid-body and consists of seven to nine cirri. Left marginal row consists of approximately six cirri. Transverse cirri about 20 μm long. Four dorsal kineties with dorsal bristles distinctly long.
Distribution. Europe, India, Japan, USA, South America, and Korea.
Remarks. *Quadristicha setigera* is characterized in life by the small body size and the long dorsal bristles. Foissner (2016) transferred *Oxytricha setigera* to a new genus based on the two macronuclear nodules and one micronucleus in between. The Korean population of *Quadristicha setigera* is almost identical to the Austrian population (Foissner, 1982). *Quadristicha setigera* is very easily confused with *Monomicrocaryon* spp. However, they differ mainly in the morphogenesis of the dorsal ciliature (non-fragmenting vs. fragmenting dorsal kinety 3 producing kinety 4) (Foissner, 2016).
Voucher slides. Two slides with protargol-impregnated specimens were deposited at the Nakdonggang National Institute of Biological Resources (NNIBRPR11688, NNIBRPR11689).

Family Amphisiellidae Jankowski, 1979
Genus *Lamtostyla* Buitkamp, 1977

3. *Lamtostyla decorata* Foissner *et al*., 2002 (Fig. 3)

Material examined. Terrestrial moss collected from Mt. Odaesan, Odaesan-ro, Jinbu-myeon, Pyeongchang-gun, Gangwon-do, Korea (N 37°43′53.2″, E 128°35′23.4″) on 28 April 2018.
Diagnosis. Size in vivo 100–150 × 20–30 μm (n = 3). Body ellipsoid to elongate ellipsoid with both ends rounded and margins parallel. Two macronuclear nodules and two or three micronuclei attached to macronuclear nod-

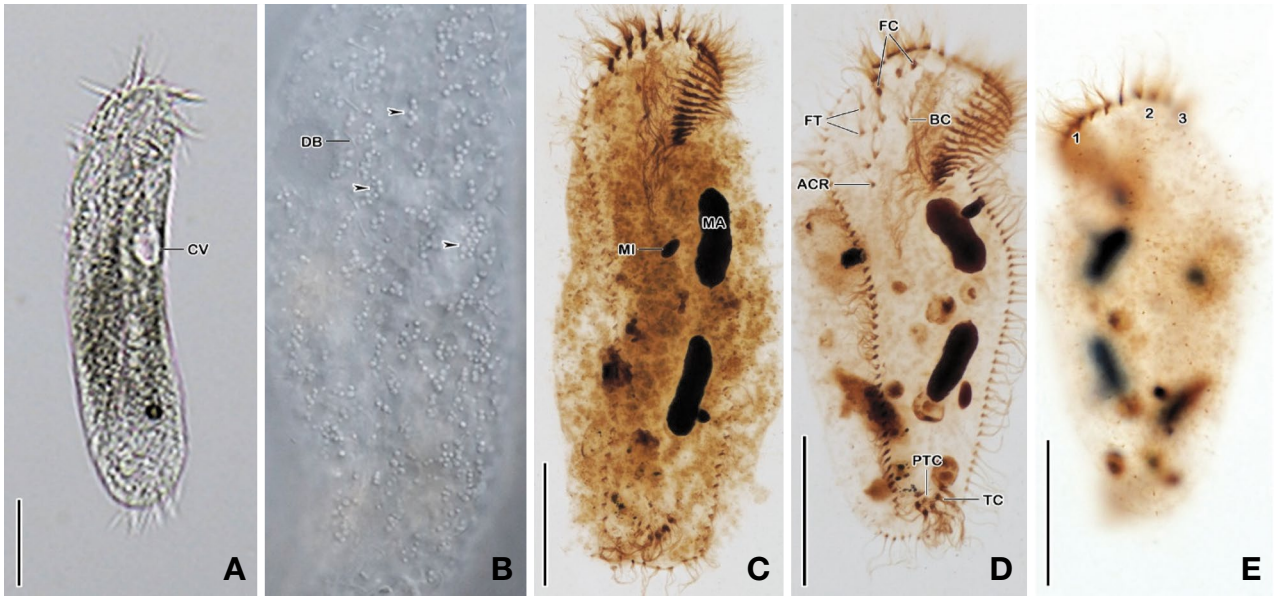

Fig. 3. *Lamtostyla decorata* from life (A, B) and after protargol impregnation (C–E). A. Typical body shape in vivo. B. Dorsal bristles and cortical granules (arrowheads). C, D. Somatic and oral ciliature of ventral sides. E. Dorsal kineties. 1–3, dorsal kineties; ACR, amphisiellid median cirral row; BC, buccal cirrus; CV, contractile vacuole; DB, dorsal bristles; FC, frontal cirri; FT, frontoterminal cirri; MA, macronucleus; MI, micronucleus; PTC, pretransverse cirri; TC, transverse cirri. Scale bars = 30 μm.

ules. Contractile vacuole on left side anterior to mid-body. Cortical granules in groups around cirri, dorsal bristles, and randomly scattered between dorsal kineties, about 0.5 μm in size. Cytoplasm colorless. Adoral zone of membranelles about 20–25% of body length. Three frontal cirri, single buccal cirrus, amphisiellid median cirral row consists of two cirri, usually three cirri left and anterior to amphisiellid median cirral row, and two frontoterminal cirri. Two pretransverse and five transverse cirri near cell end. Right and left marginal rows composed of 41–46 and 47–51 cirri, respectively, anterior portion of right marginal row on dorsal side. Three dorsal kineties. Caudal cirri lacking.

Distribution. Australia, Austria, Namibia, and Korea.

Remarks. The Korean population of *L. decorata* fits the description of the type population by Foissner *et al.* (2002). It is also very similar to *L. granulifera* Foissner, 1997 especially in the number of the right and left marginal cirri (41–46 and 47–51 vs. 39–49 and 42–52, respectively). However, this character has proved to be less important because the Korean population (Kim *et al.*, 2016) has slightly overlapping right (34–42) and non-overlapping left (33–38) marginal cirri. The most important difference between the two species is the arrangement of the cortical granules (groups around cirri, dorsal bristles, and randomly scattered between dorsal kineties in *L. decorata* vs. inconspicuous and very closely spaced rows on ventral and dorsal side in *L. granulifera*) (Foissner, 1997; Kim *et al.*, 2016). *Lamtostyla longa* (Hemberger, 1985) Berger & Foissner, 1988 is also similar to *L. decorata* but differs mainly in having fewer right and left marginal cirri (23 and 21 vs. 44 and 49, respectively) and the number of dorsal kineties (five vs. three).

Voucher slides. One slide with protargol-impregnated specimens was deposited at the Nakdonggang National Institute of Biological Resources (NNIBRPR11675).

4. *Lamtostyla islandica* Berger & Foissner, 1988 (Fig. 4)

Material examined. Terrestrial soil collected from Mt. Jeombongsan, Jindong-ri, Girin-myeon, Inje-gun, Gangwon-do, Korea (N 38°02′10.3″, E 128°26′11.3″) on 8 July 2018.

Diagnosis. Size in vivo about 50–80 × 15–20 μm (n = 3). Body elongate elliptical with parallel margins. Two macronuclear nodules and two micronuclei each attached to a macronucleus nodule. Cortical granules lacking. Cytoplasm colorless. Adoral zone of membranelles about 20% of body length. Ventral cirri reduced in number, consists of three frontal cirri, a single buccal cirrus, three cirri left to the anterior part of the short amphisiellid median cirral row, and only three transverse cirri near cell end. Three dorsal kineties. Caudal cirri lacking.

Distribution. Australia, Austria, Brazil, Iceland, Namibia, and Korea.

Remarks. The Korean population of *L. islandica* fits the description of its type population (Berger and Foissner, 1988). It is also similar to *L. perisincirra* in the body

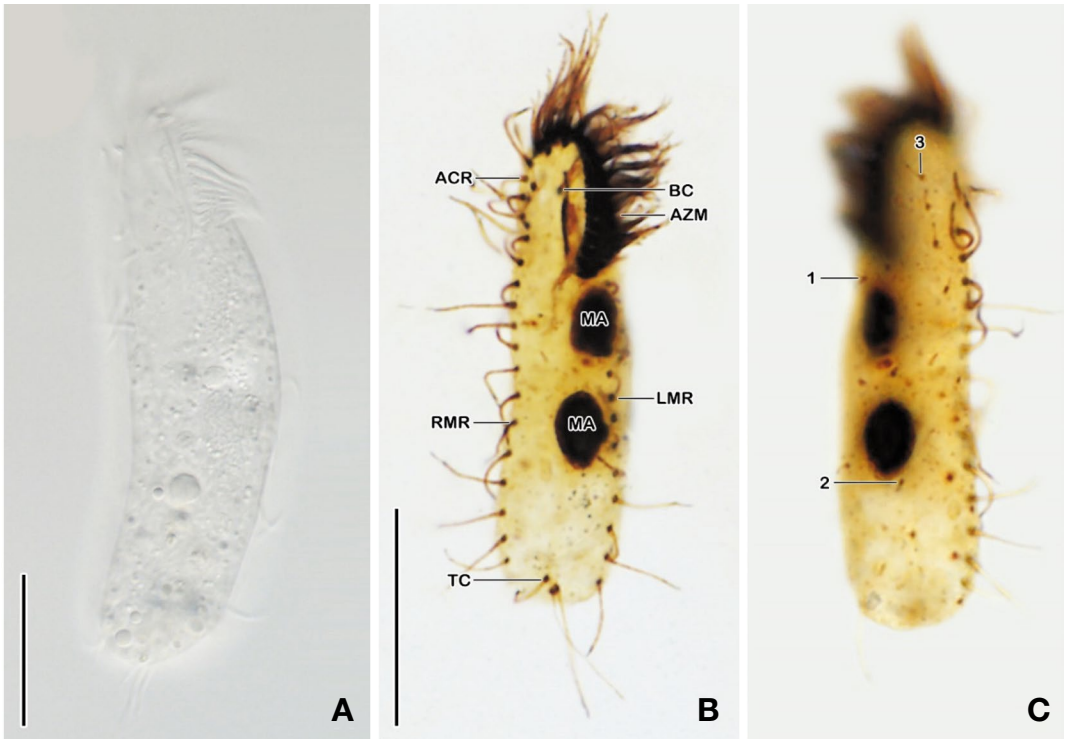

Fig. 4. *Lamtostyla islandica* from life (A) and after protargol impregnation (B, C). A. Body shape in vivo. B. Somatic and oral ciliature of ventral side. C. Dorsal kineties and right marginal cirri. 1–3, dorsal kineties; ACR, amphisiellid median cirral row; AZM, adoral zone of membranelles; BC, buccal cirrus; LMR, left marginal row; MA, macronuclear nodules; RMR, right marginal row; TC, transverse cirri. Scale bars = 20 μm.

size and the ventral ciliature (Berger and Foissner, 1987). However, the two species differ mainly in the number (two vs. one) and location (each attach to a macronuclear nodule vs. between macronuclear nodules) of micronuclear nodules and the number of transverse cirri (three vs. three or four).

Voucher slides. Two slides with protargol-impregnated specimens were deposited at the Nakdonggang National Institute of Biological Resources (NNIBRPR11676, NNIBRPR11677).

5. *Lamtostyla longa* (Hemberger, 1985) Berger & Foissner, 1988 (Fig. 5)

Material examined. Terrestrial moss collected from Mt. Yeonhwasan, Sinbun-ri, Yeonghyeon-myeon, Goseong-gun, Gyeongsangnam-do, Korea (N 35°4′8.2″, E 128°13′47.1″) on 4 February 2019.

Diagnosis. Size 50–60 × 15–20 μm after protargol impregnation (n = 3). Body ellipsoid with both ends rounded and margins parallel. Two macronuclear nodules and two micronuclei each attached to a macronuclear nodule. Contractile vacuole slightly left to body center. Cortical granules lacking. Cytoplasm colorless. Adoral zone of membranelles about 25% of body length. Three frontal cirri, single buccal cirrus, amphisiellid median cirral row consists of two cirri, usually three cirri left and anterior to amphisiellid median cirral row. Two frontoterminal cirri. Two pretransverse and five transverse cirri near cell end. Right and left marginal rows composed of 14–17 and 14–18 cirri, respectively, anterior portion of right marginal row on dorsal side. Three dorsal kineties. Caudal cirri lacking.

Distribution. Peru and Korea.

Remarks. The Korean population of *L. longa* fits the description of the type population by Hemberger (1985). However, the size of the Korean population is slightly smaller (50–60 × 15–20 vs. 103 μm after protargol impregnation, Figure 19 in Hemberger (1985)). Moreover, it is not known if the type population possesses cortical granules, which is clearly absent in the Korean population. *Lamtostyla longa* is similar to *L. raptans* in the lack of cortical granules and in having five transverse cirri, amphisiellid cirral row composed of only four cirri, and five dorsal kineties. The two species differ mainly in the body size (< 100 vs. about 200 μm), the number of cirri in the right and left (14–17 and 14–18 vs. 57–68, and 60–62, respectively) marginal cirri (Hemberger, 1985).

Voucher slides. Two slides with protargol-impregnated specimens were deposited at the Nakdonggang National

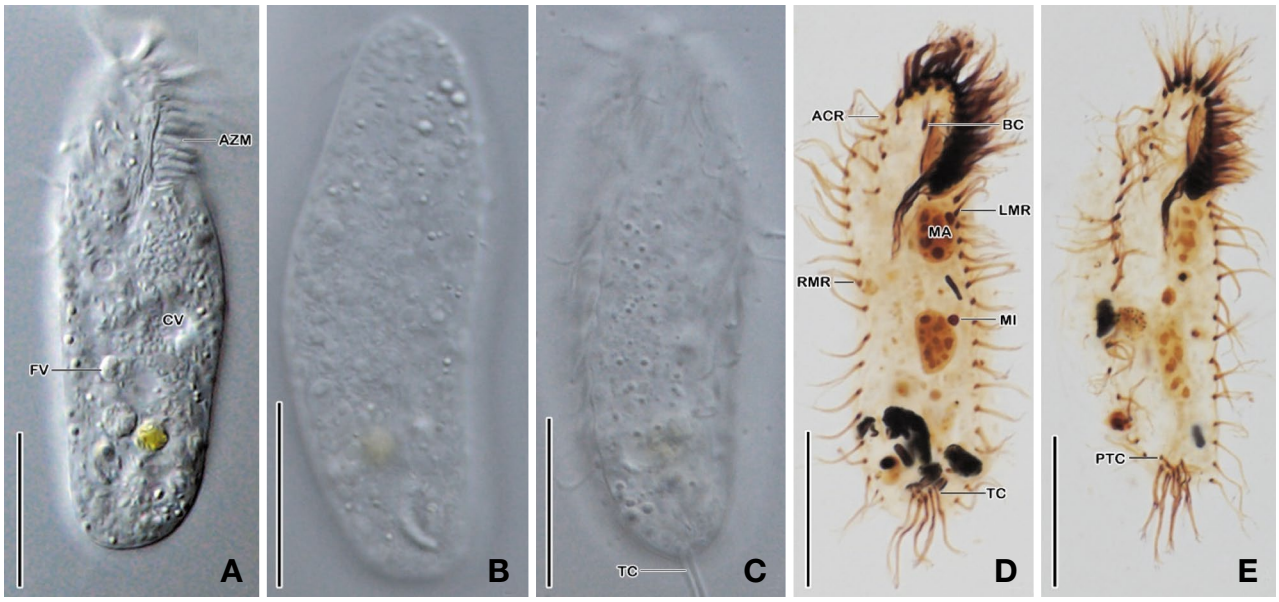

Fig. 5. *Lamtostyla longa* from life (A–C) and after protargol impregnation (D, E). A. Typical body shape in vivo. B, C. Dorsal and ventral views showing the lack of cortical granules absent. D, E. Somatic and oral ciliature on ventral side. ACR, amphisiellid median cirral row; AZM, adoral zone of membranelles; BC, buccal cirrus; CV, contractile vacuole; FV, food vacuole; LMR, left marginal row; MA, macronuclear nodule; MI, micronucleus; PTC, pretransverse cirri; RMR, right marginal row; TC, transverse cirri. Scale bars = 20 μm.

Institute of Biological Resources (NNIBRPR11678, NNI BRPR11679).

Order Urostylida Jankowski, 1979
Family Urostylidae Bütschli, 1889
Genus *Anteholosticha* Berger, 2003

6. *Anteholosticha brachysticha* Berger, 2003 (Fig. 6)

Material examined. Terrestrial moss collected from Mt. Yeonhwasan, Sinbun-ri, Yeonghyeon-myeon, Goseong-gun, Gyeongsangnam-do, Korea (N 35°4′8.2″, E 128°13′ 47.1″) on 4 February 2019.
Diagnosis. Size in vivo 80–90 × 15–20 (n = 3). Body elongate elliptical, margins parallel. Nuclear apparatus composed of 21–32 globular or ellipsoidal macronuclear nodules and two micronuclei. Cortical granules colorless, 0.4–1.0 μm in size, arranged in groups around dorsal bristles and posterior to bases of ventral cirri. Cytoplasm colorless. Adoral zone of membranelles about 30% of body length. Ventral cirri reduced in number, three frontal cirri, a single buccal cirrus, two frontoterminal cirri, midventral complex composed of four to seven pairs and ends at level of proximal end of adoral zone of membranelles. Two or four transverse cirri near cell end. Right and left marginal rows composed of 20–22 and 17–24 cirri, respectively. Three dorsal kineties. Caudal cirri lacking.
Distribution. Costa Rica, Namibia, and Korea.
Remarks. The Korean population of *A. brachysticha* fits the description of the type population by Foissner *et al.* (2002) except of the colorless (vs. yellowish) cortical granules. It is also similar to *A. bergeri* in the body size and the ventral ciliature (Foissner, 1987). However, they differ mainly in the color of cortical granules (colorless vs. pink), the number of macronuclear nodules (30 vs. 15 on average), and the starting point of right marginal row (at level of buccal cirrus vs. at level of proximal end of adoral zone of membranelles).
Voucher slides. Two slides with protargol-impregnated specimens were deposited at the Nakdonggang National Institute of Biological Resources (NNIBRPR11666, NNIBRPR116667).

Genus *Pseudobirojimia* Foissner, 2016

7. *Pseudobirojimia muscorum* (Kahl, 1932) Foissner, 2016 (Fig. 7)

Material examined. Terrestrial moss collected from Mt. Odaesan, Odaesan-ro, Jinbu-myeon, Pyeongchang-gun, Gangwon-do, Korea (N 37°43′53.2″, E 128°35′23.4″) on 28 April 2018.
Diagnosis. Size 140–160 × 20–25 μm after protargol impregnation (n = 3). Body slender and elongate ellipsoid with posterior end narrower than anterior. 51–56 macronuclear nodules. Contractile vacuole slightly left and anterior to body center. Cortical granules colorless, ellipsoid, arranged in short rows around dorsal bristles.

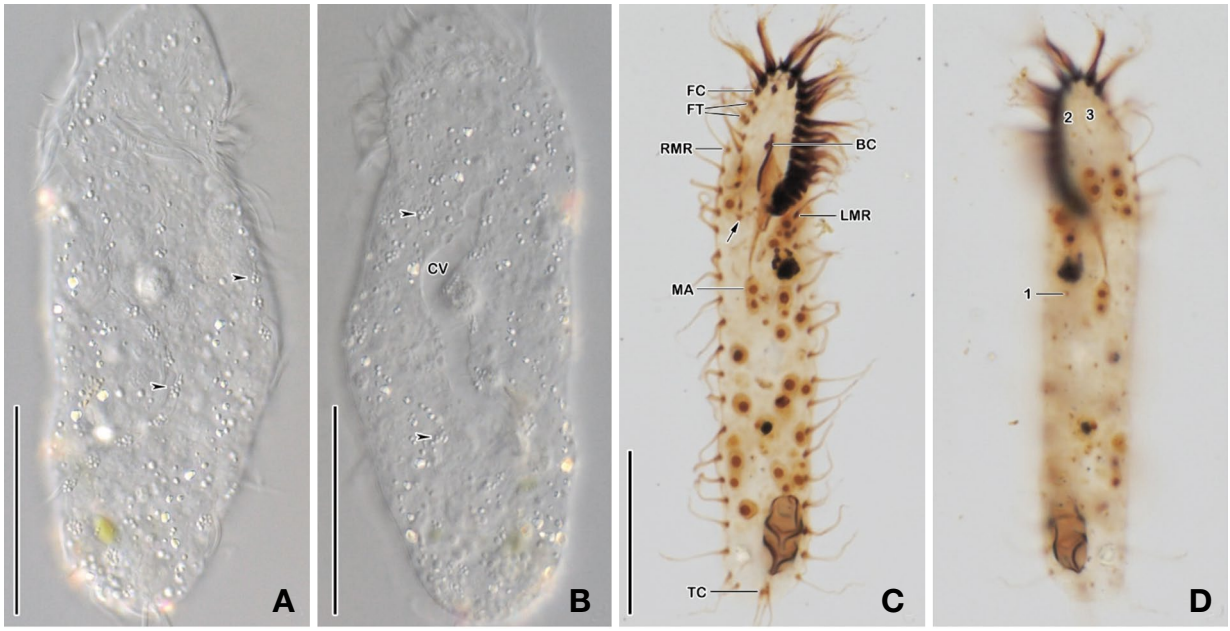

Fig. 6. *Anteholosticha brachysticha* from life (A, B) and after protargol impregnation (C, D). A. Cortical granulation on ventral side (arrowheads). B. Cortical granulation on dorsal side (arrowheads) and contractile vacuole. C. Somatic and oral ciliature on ventral side with distribution of macronuclear nodules. Arrow marks last midventral cirrus. D. Dorsal kineties. 1–3 dorsal kineties; BC, buccal cirrus; CV, contractile vacuole; FC, frontal cirri; FT, frontoterminal cirri; LMR, left marginal row; MA, macronucleus nodule; RMR, right marginal row; TC, transverse cirri. Scale bars = 30 μm (A, B); 20 μm (C).

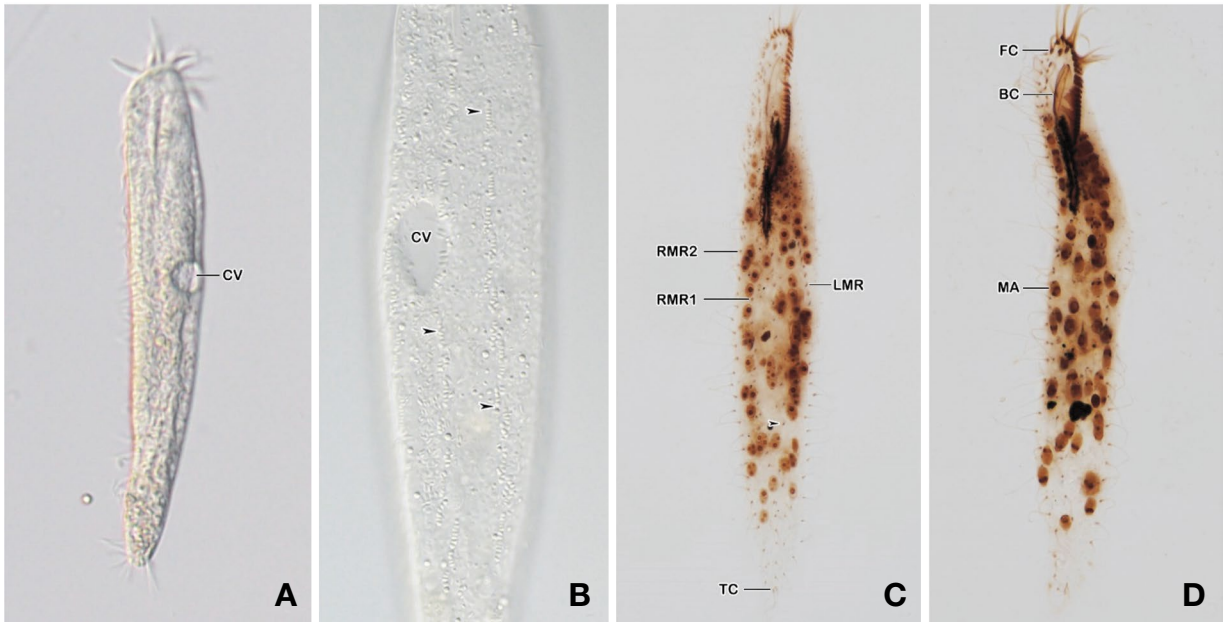

Fig. 7. *Pseudobirojimia muscorum* from life (A, B) and after protargol impregnation (C, D). A. Slender body shape in vivo. B. Cortical granulation on dorsal side. C, D. Ventral ciliatures. BC, buccal cirrus; CV, contractile vacuole; FC, frontal cirri; LMR, left marginal row; MA, macronucleus nodule; RMR1, 2, inner and outer right marginal rows; TC, transverse cirri. Scale bars = 50 μm.

Cytoplasm colorless. Adoral zone of membranelles about 25% of body length. Three frontal cirri, one buccal cirrus, midventral complex consists of six or seven midventral pairs and 13–16 midventral cirri. Two fron-

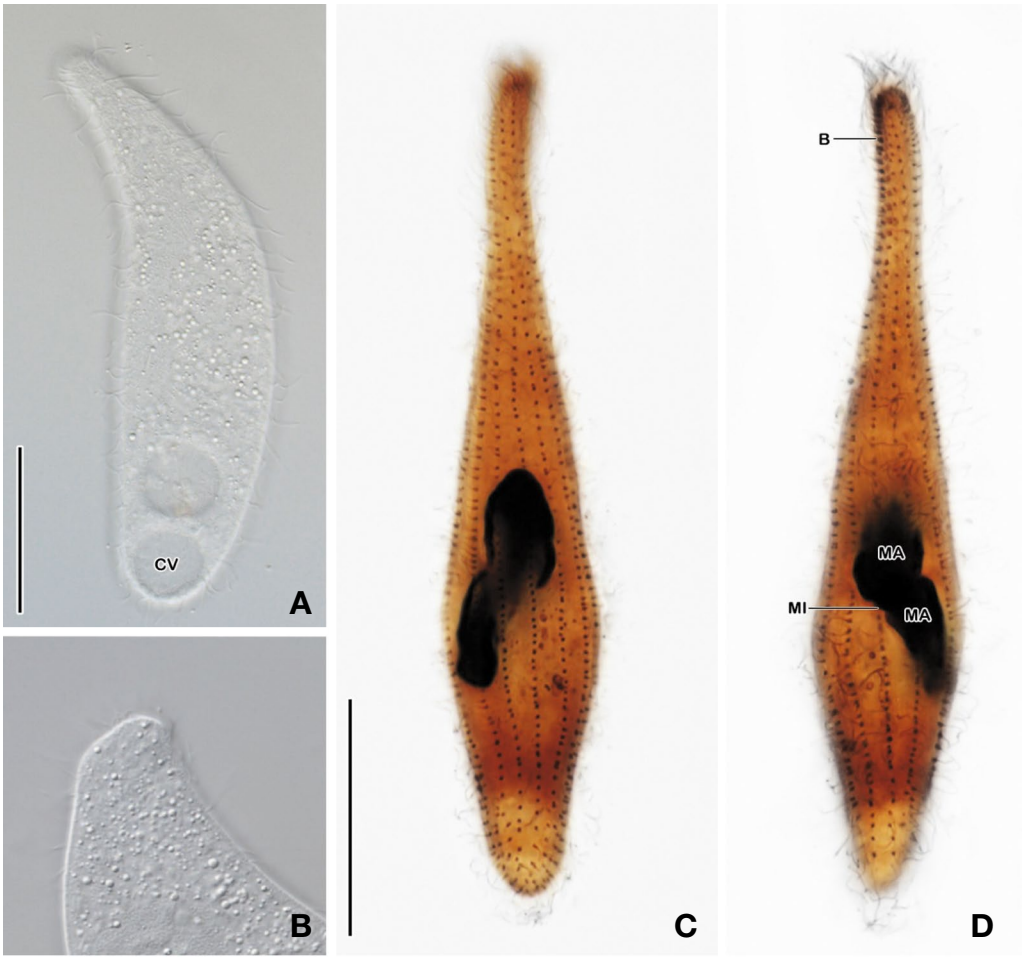

Fig. 8. *Apocoriplites lajacola* from life (A, C) and after protargol impregnation (C, D). A. Arrangement of cortical granules and contractile vacuole. B. Oral region showing the lack of extrusomes. C. Somatic ciliature and nuclear apparatus. D. Dorsal brush rows and somatic kineties. B, brush rows; CV, contractile vacuole; MA, macronucleus nodules; MI, micronucleus. Scale bars = 30 μm.

toterminal cirri. Usually four transverse cirri near cell end. Inner right marginal row consists of 33–47 cirri, outer row of 33–37 cirri, and left marginal row consists of 41–45 cirri.

Distribution. Amazonia, Australia, Austria, Chile, Germany, Kenya, Marion Islands, Namibia, and Korea.

Remarks. The Korean population of *Pseudobirojimia muscorum* fits the description by Foissner (1982) in almost all characters. According to Foissner (2016), *Pseudobirojimia muscorum* differs from other Holostichidae by the presence (vs. absence) of the midventral cirral row. It also differs from the family Bakuellidae by having one left and two right marginal cirral rows and continuous adoral zone of membranelles.

Voucher slides. One slide with protargol-impregnated specimens were deposited at the Nakdonggang National Institute of Biological Resources (NNIBRPR11685).

Class Litostomatea Small & Lynn, 1981
Subclass Haptoria Corliss, 1974
Order Haptorida Corliss, 1974
Family Fuscheriidae Foissner *et al*., 2002
Genus *Apocoriplites* Oertel *et al*., 2008

8. *Apocoriplites lajacola* Oertel *et al*., 2008 (Fig. 8)

Material examined. Terrestrial soil collected from Jibyeon-gil, Gangneung-si, Gangwon-do, Korea (N 37°46′ 26″, E 128°52′15″) on 26 February 2019.

Diagnosis. Size about 100 × 30 μm in vivo (n = 3). Body cylindroidal to elongate bursiform. Cytoplasm colorless. Extrusomes lacking. Contractile vacuole terminal. Minute cortical granules arranged in rows between ciliary rows. Two globular macronuclear nodules with a micronucleus in between. 10–12 ciliary rows, two anteriorly differentiated into isostichad dorsal brush occupying about 23% of

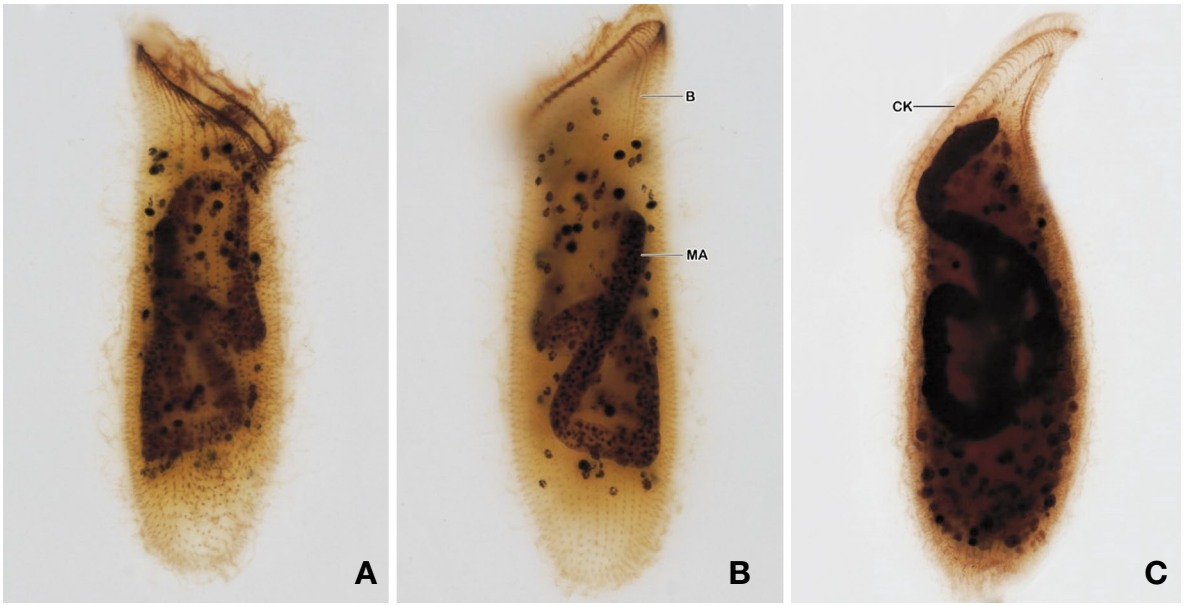

Fig. 9. *Epispathidium amphoriforme* after protargol impregnation. A. Right side view to show circumoral kinety and somatic kineties. B, C. Left side views to show dorsal brush rows, ribbon-like macronucleus and spherical inclusions. B, brush rows; CK, circumoral kinety; MA, macronucleus. Scale bars = 30 μm.

body length and composed of widely spaced dikinetids.
Distribution. Venezuela and Korea.
Remarks. The genera *Coriplites* and *Apocoriplites* are characterized by the absence of the extrusomes (Foissner, 2016). *Apocoriplites* is a monotypic genus. Thus *A. lajacola* can be compared only with the species belong to the genus *Coriplites*, which are characterized by having three brush rows (Oertel *et al*., 2008).
Voucher slides. Two slides with protargol-impregnated specimens were deposited at the Nakdonggang National Institute of Biological Resources (NNIBRPR11660, NNIBRPR11661).

Family Spathidiidae Kahl in Doflein & Reichewnow, 1929
Genus *Epispathidium* Foissner, 1984

9. *Epispathidium amphoriforme* (Greeff, 1888) Foissner, 1984 (Fig. 9)

Material examined. Terrestrial moss collected from Mt. Yeonhwasan, Sinbun-ri, Yeonghyeon-myeon, Goseong-gun, Gyeongsangnam-do, Korea (N 35°4′8.2″, E 128°13′47.1″) on 4 February 2019.
Diagnosis. Body size 110−156 × 32−49 μm after protargol impregnation (n = 3). Body typical spathidiid shape, i.e. oral bulge moderately spatulate, mid-body slightly swollen. Ribbon-like macronucleus. Three dorsal brush rows; single circumoral kinety; about 45 somatic kineties anteriorly curved and parallel to circumoral kinety. Single contractile vacuole centrally located at posterior end.
Distribution. Austria and Korea.
Remarks. The Korean population of *E. amphoriforme* is most similar to an Austrian (from Zillertal, Tyrol) population described by Kahl (1930) especially in the number of somatic kineties (about 45 vs. 40−50). It is also very similar to another Austrian (from Lower Austria) population described by Foissner (1984) but differs mainly in the number of somatic kineties (about 45 vs. 24−38) and the absence (vs. presence) of spindle-like extrusomes (Foissner, 1984).
Voucher slides. Two slides with protargol-impregnated specimens were deposited at the Nakdonggang National Institute of Biological Resources (NNIBRPR11670, NNIBRPR11671).

Genus *Protospathidium* Dragesco & Dragesco-Kernéis, 1979

10. *Protospathidium muscicola* Dragesco & Dragesco-Kernéis, 1979 (Fig. 10)

Material examined. Terrestrial moss collected from Mt. Galmobong, Idang-ri, Goseong-eup, Goseong-gun, Gyeongsangnam-do, Korea (N 34°58′16.1″, E 128°16′04.3″) 4 February 2019.
Diagnosis. Size in vivo about 90 × 20 μm (n = 5). Body very narrowly ellipsoidal or spatulate. Nuclear apparatus composed of scattered macronuclear nodules and micro-

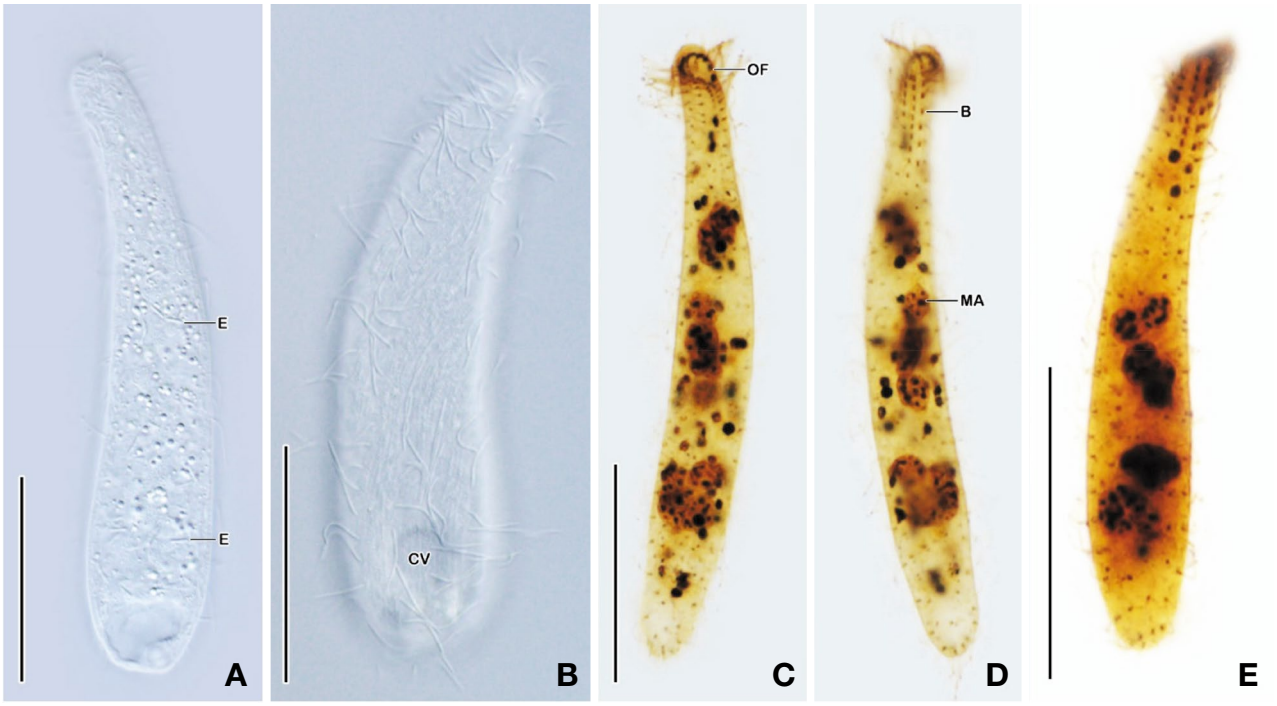

Fig. 10. *Protospathidium muscicola* from life (A, B) and after protargol impregnation (C–E). A. Typical body shape to show oral and cytoplasmic extrusomes with one terminal contractile vacuole. B. Cortical granules and apparatus of dorsal brush rows. C, D. Somatic and circumoral kineties with macronuclear nodules. E. Details of dorsal brush rows. B, brush rows; CV; contractile vacuole; E, extrusomes; MA, macronuclear nodule; OF, oral kinetofragment. Scale bars = 30 μm.

nuclei. Contractile vacuole terminal. Cytoplasm colorless. Extrusomes studded in oral bulge and scattered in cytoplasm, rod shaped. Cortical granules minute and arranged in rows between ciliary rows. About 10 somatic ciliary rows. Dorsal brush consists of three rows, row 1 short, row 2 long up to 20% of body length.

Distribution. Austria, Benin, Botswana, South Africa, Venezuela, and Korea.

Remarks. The Korean population of *Protospathidium muscicola* is consistent with other populations described by Foissner and Xu (2007) and Dragesco and Dragesco-Kernéis (1979). However, it is most similar to the Venezuelan population in the body size and the number of ciliary rows (Foissner and Xu, 2007). The Austrian population is much smaller (65 × 10 μm after protargol impregnation) and has rather fewer (8 on average) ciliary rows (Foissner and Xu, 2007).

Voucher slides. One slide with protargol-impregnated specimens were deposited at the Nakdonggang National Institute of Biological Resources (NNIBRPR11684).

Family Lacrymariidae de Fromentel, 1876
Genus *Phialinides* Foissner, 1988

11. *Phialinides australis* Foissner, 1988 (Fig. 11)

Material examined. Terrestrial soil collected from Mt. Jeombongsan, Jindong-ri, Girin-myeon, Inje-gun, Gangwon-do, Korea (N 38°02′10.3″, E 128°26′11.3″) on 8 July 2018.

Diagnosis. Size in vivo about 90 × 20 μm (n = 3). Body elongate elliptical clavate with widest portion posterior to neck; highly contractile, length: width ratio 4–5:1. Two macronuclear nodules in mid-body, micronucleus indistinct. Contractile vacuole terminal. Extrusomes form conspicuous bundles in oral bulge and in anterior half of cell. Cortex flexible, contains many minute cortical granules. About 13 somatic ciliary rows, individual rows composed of dikinetids anteriorly and monokinetids posteriorly. Few basal bodies (ciliary wreath) around the short neck.

Distribution. Africa, Australia, Central America, South America, and Korea.

Remarks. The Korean population of *Phialinides australis* agrees with the type population (Foissner, 1988). To date, only four *Phialinides* species have been described (*P. armatus*, *P. australis*, *P. muscicola*, and *P. bicaryomorphus*). *Phialinides australis* differs from *P. armatus* in the shape of the extrusomes (rod shaped vs. drumstick) and the number of macronucleus nodules (2 vs. ~15). *Phialinides australis* also differs from *P. bicaryomorphus* in having less number (13 vs. 23 on average) of ciliary rows and different shape (ellipsoid to globular vs. discoid and

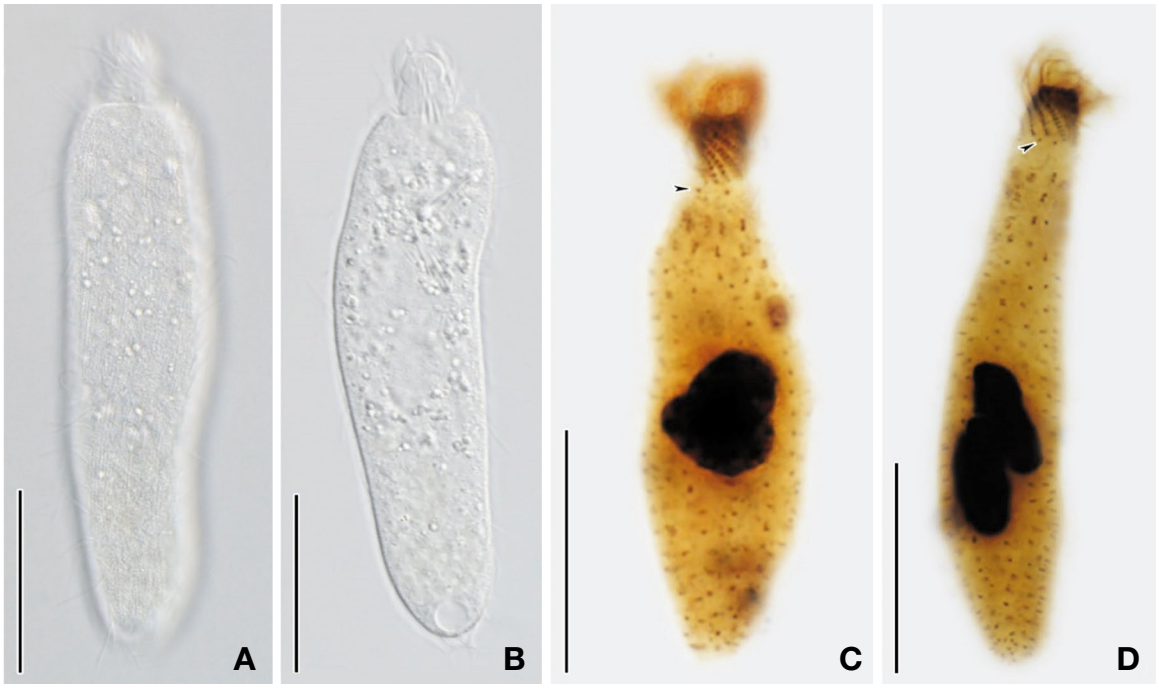

Fig. 11. *Phialinides australis* from life (A, B) and after protargol impregnation (C, D). A. Cortical granulation. B. Oral and cytoplasmic extrusomes. C, D. Details of oral and somatic ciliature and the phialinid ciliary wreath (arrowheads). Scale bars = 30 μm (A, B); 20 μm (C, D).

flattened in middle) and number (two vs. one) of macronuclear nodules. It also differs from *P. muscicola* and *P. bicaryomorphus* in the size (small vs. large) of the cortical granules (Foissner *et al*., 2002; Foissner and Wenzel, 2004; Foissner, 2016).

Voucher slides. Two slides with protargol-impregnated specimens were deposited at the Nakdonggang National Institute of Biological Resources (NNIBRPR11682, NNI BRPR11683).

Family Pseudoholophryidae Berger *et al*., 1984
Genus *Paraenchelys* Foissner, 1983

12. *Paraenchelys wenzeli* Foissner, 1984 (Fig. 12)

Material examined. Terrestrial moss collected from Mt. Yeonhwasan, Sinbun-ri, Yeonghyeon-myeon, Goseong-gun, Gyeongsangnam-do, Korea (N 35°4′8.2″, E 128°13′47.1″) on 4 February 2019.

Diagnosis. Size about 105 × 40 μm in vivo and 80–125 × 21–45 μm after protargol impregnation (n = 3). Body shape pyriform. Extrusomes scattered on whole body, teardrop shape, conspicuously large about 15 × 2 μm in vivo. Cortical granules ellipsoidal, regularly arranged, and about 0.6 × 0.4 μm. Single sausage-like shape macronucleus. 55–77 somatic kineties. Dorsal brush rows irregularly fragmented.

Distribution. Austria, Germany, Namibia, Singapore, Turkey, and Korea

Remarks. The Korean population of *P. wenzeli* differs from both the type population (Foissner, 1984) and the Turkish population (Senler and Yildiz, 2009) only in the number of somatic kineties (55–77 vs. 32–53 and 34–45, respectively). *Paraenchelys wenzeli* is distinguishable from *P. terricola* by the length of extrusome (15 μm vs. 10 μm on average) and the shape of macronucleus (sausage-like vs. ellipsoidal) (Foissner, 1984).

Voucher slides. Two slides with protargol-impregnated specimens were deposited at the Nakdonggang National Institute of Biological Resources (NNIBRPR11680, NNIBRPR116801).

Family Tracheliidae Ehrenberg, 1838
Genus *Rimaleptus* Foissner, 1984

13. *Rimaleptus similis* (Foissner, 1995) Vd'ačný & Foissner, 2012 (Fig. 13)

Material examined. Terrestrial moss collected from Mt. Yeonhwasan, Sinbun-ri, Yeonghyeon-myeon, Goseong-gun, Gyeongsangnam-do, Korea (N 35°4′6.4″, E 128°13′53.5″) on 4 February 2019.

Diagnosis. Size in vivo 260–280 × 50–60 μm and about 135 × 35 μm after protargol impregnation (n = 3). Body narrowly dileptid with rounded posterior end, proboscis length 130–170 μm in vivo. A single micronucleus in

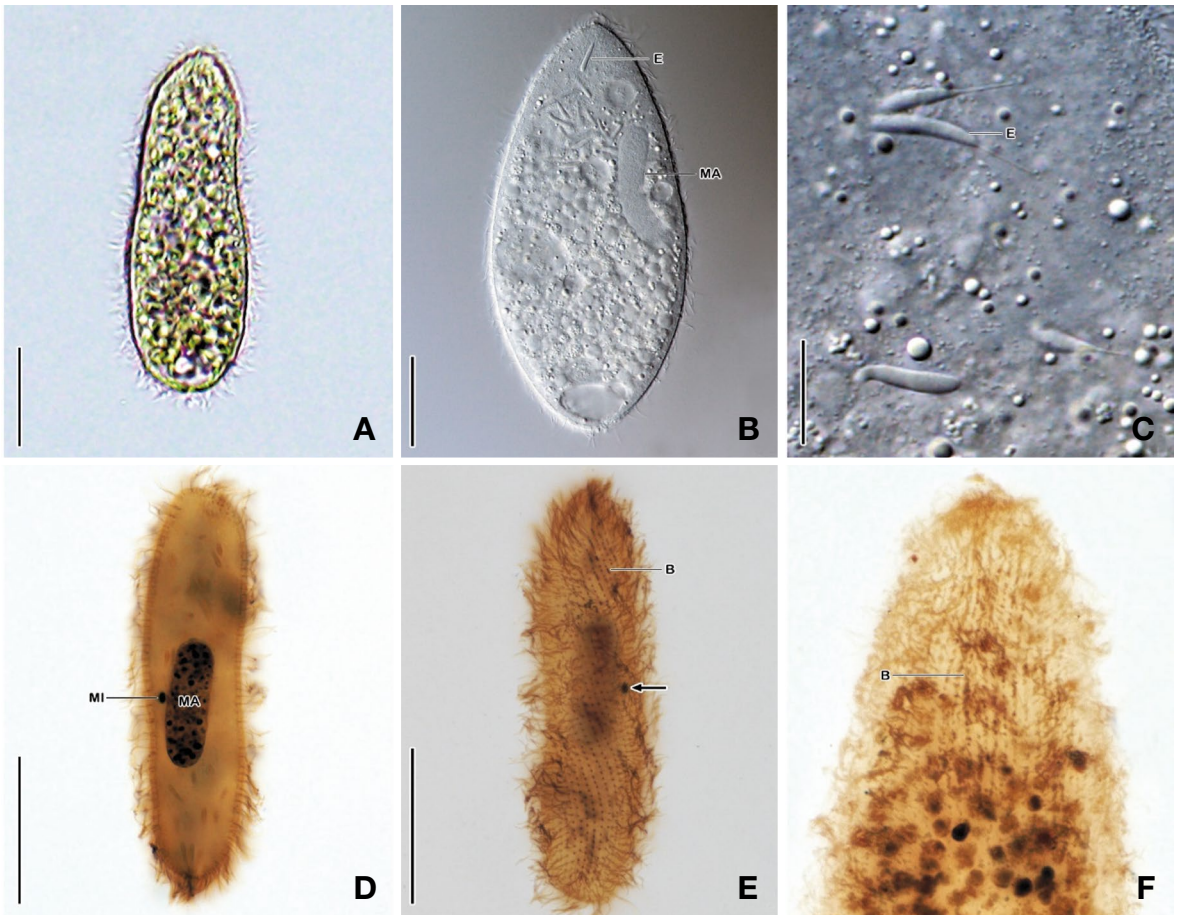

Fig. 12. *Paraenchelys wenzeli* from life (A–C) and after protargol impregnation (D–F). A. Typical body shape in vivo. B. Details of cytoplasmic structures including macronucleus, extrusomes and contractile vacuoles. C. Peculiar large, teardrop shape extrusomes. D. Macronucleus with micronucleus and weakly impregnated large extrusomes. E. Somatic and oral ciliature (arrow indicates micronucleus). F. Details of fragmented dorsal brush rows. B, brush rows; E, extrusomes; MA, macrnucleus; MI, micronucleus. Scale bars = 30 μm (A, B, D, E); 10 μm (C).

between two oblong macronuclear nodules. Contractile vacuoles located on dorsal side in a row. Two types of extrusomes attached to proboscis and oral bulge: type I rod-shaped, about 9.0 × 0.7 μm in size; type II oblong, about 3 μm in length. 29–36 somatic kineties; preoral kineties oblique, ordinarily to narrowly spaced, each usually composed of two or three narrowly spaced kinetids.
Distribution. Australia, Costa Rica, Kenya, Namib Desert, and Korea
Remarks. The Korean population of *R. similis* corresponds to the original population (Foissner, 1995; Vd'ačný and Foissner, 2012). *Rimaleptus similis* is similar to the most related species, *R. orientalis* (Song *et al.*, 1988) Vd'ačný & Foissner, 2012, in the arrangement of contractile vacuoles (only on dorsal side), the shape of macronuclear nodules (ellipsoid to oblong), and in the short brush bristles (~3 μm) but they differ mainly in the shape (rod-shaped vs. broadly fusiform) and size (6–10 μm vs. 1–2 μm) of oral extrusomes (Vd'ačný and Foissner, 2012).
Voucher slides. Two slides with protargol-impregnated specimens were deposited at the Nakdonggang National Institute of Biological Resources (NNIBRPR11690, NNI BRPR11691).

Class Nassophorea Small & Lynn, 1981
Order Microthoracida Jankowski, 1967
Family Microthoracidae Wrzesniowski, 1870
Genus *Drepanomonas* Fresenius, 1858

14. *Drepanomonas revoluta* Penard, 1922 (Fig. 14)

Material examined. Terrestrial soil collected from Mt. Hambaeksan, Hyeol-dong, Taebaek-si, Gangwon-do, Korea (N 37°9′23.8″, E 128°54′59.3″) on 17 May 2018.
Diagnosis. Size in vivo 25–30 × 10–15 μm (n = 5). Body semi ellipsoidal. One macronucleus and one micronucleus. Cortex rigid, right side smooth except of minute

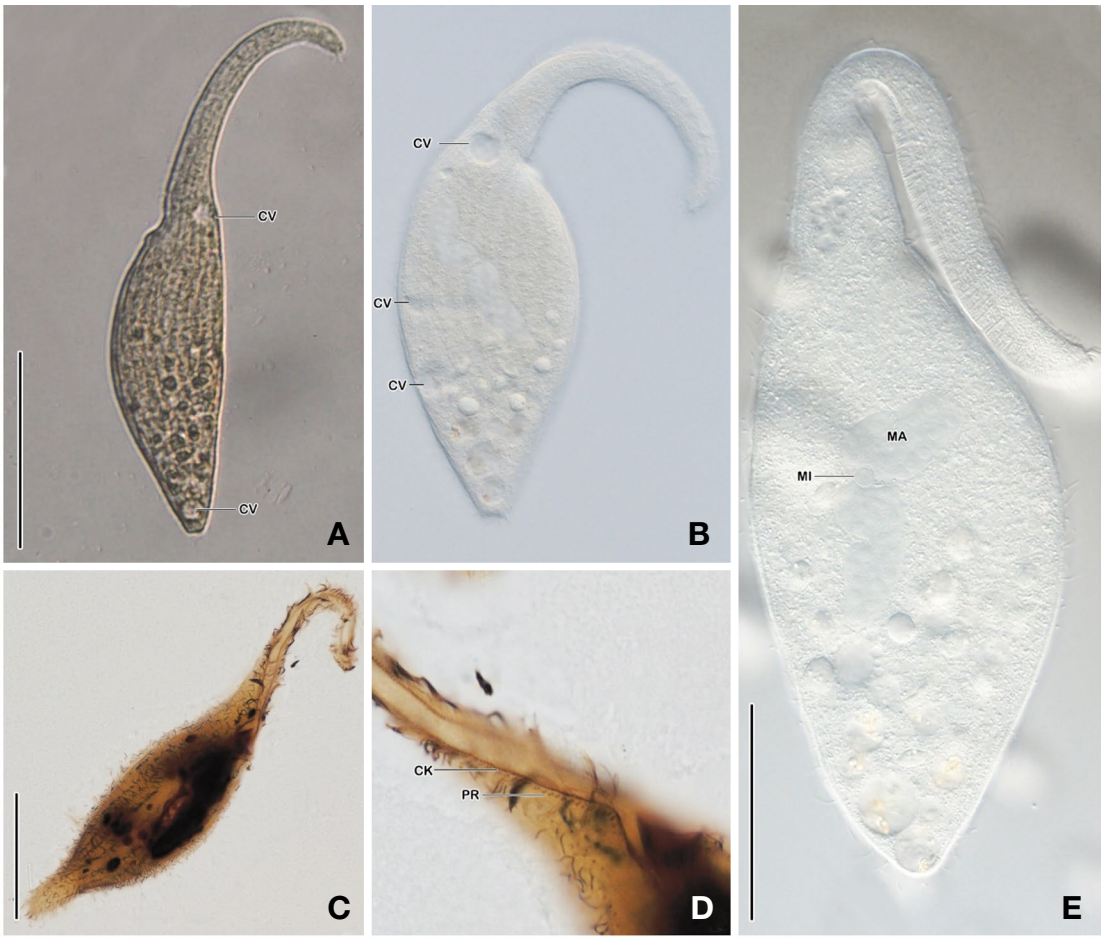

Fig. 13. *Rimaleptus similis* from life (A, B, E) and after protargol impregnation (C, D). A. Typical body shape in vivo. B. Distribution of contractile vacuoles. C. Somatic and oral ciliature. D. Details of oral ciliature. E. Single spherical micronucleus between two macronuclear nodules and two kinds of oral extrusomes. CK, circumoral kinety; CV, contractile vacuoles; MA, macronuclear nodule; MI, micronucleus; PR, preoral kinety. Scale bars = 100 μm (A); 50 μm (C, E).

crenellation along ciliary rows. Left side with longitudinal, deep, and wide furrow. Contractile vacuole slightly posterior and dorsal to oral structures. Cytopyge posterior and left to contractile vacuole. Extrusomes lenticular and left of somatic kineties. Cytoplasm colorless with minute lipid droplets and food vacuoles containing bacteria. Nine somatic and three preoral kineties, each somatic kinety consists of few dikinetids and few monokinetids with large gaps in the middle; preoral kineties consist of two or three dikinetids and each with a single monokinetid posteriorly. Oral apparatus in mid-body containing oral membranelles and oral primordium.

Distribution. Cosmopolitan.

Remarks. The Korean population of *D. revoluta* resembles the type population (Penard, 1922) and the Austrian population described by Foissner (1987) in the size (25−30 × 10−15 μm vs. 20−30 × 10−15 μm), shape, the ciliary pattern, and the deep, wide furrow on the left side. It is also very similar to *D. vasta* Foissner & Omar 2013 (Omar and Foissner, 2013) differing mainly in the structure of somatic kinety 4 (3 or 4 vs. only one ciliated dikinetid anteriorly), the total number of basal bodies (80 vs. 90 on average), and the body shape (distinctly flattened vs. thick) (Omar and Foissner, 2013).

Voucher slides. Two slides with protargol-impregnated specimens were deposited at the Nakdonggang National Institute of Biological Resources (NNIBRPR11668, NNIBRPR11669).

Class Colpodea Small & Lynn, 1981
Order Bryometopida Foissner, 1985
Family Bryometopidae Jankowski, 1980
Genus *Bryometopus* Kahl, 1932

15. *Bryometopus triquetrus* Foissner, 1993 (Fig. 15)

Material examined. Terrestrial moss collected from Mt. Yeonhwasan, Sinbun-ri, Yeonghyeon-myeon, Goseong-

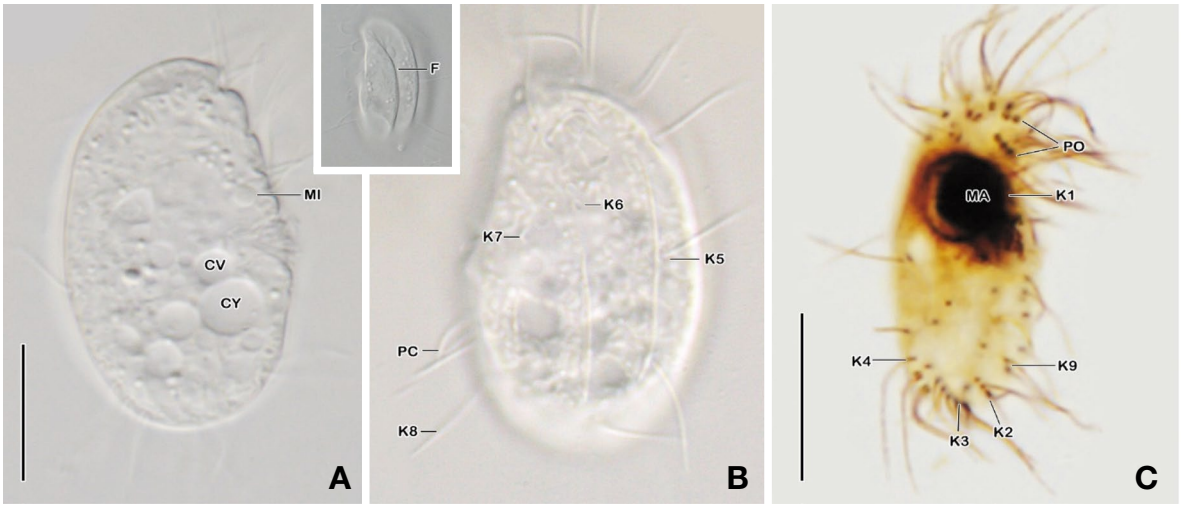

Fig. 14. *Drepanomonas revoluta* from life (A–C) and after protargol impregnation (D). A. Body outline in vivo. B. Note the deep wide furrow on the left side. C. Left side in vivo. D. Somatic and oral ciliature on right side. CV, contractile vacuole; CY, cytopyge; F, furrow; K1–9, somatic kineties; MA, macronucleus; MI, micronucleus; PC, postoral complex; PO, preoral kineties. Scale bars = 10 μm.

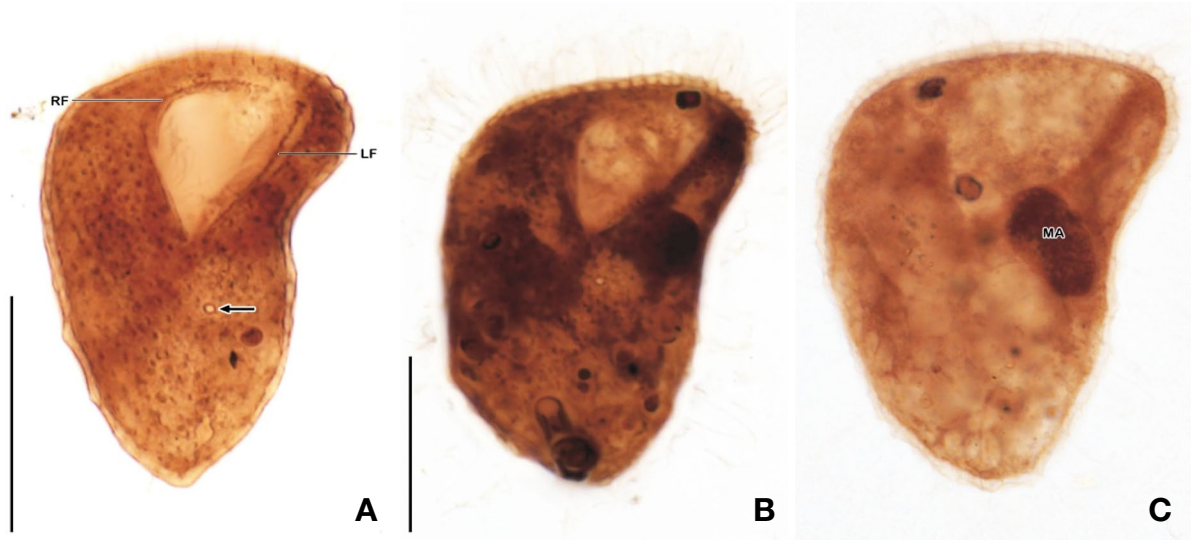

Fig. 15. *Bryometopus triquetrus* after protargol impregnation. A. Somatic ciliature and contractile vacuole pore (arrow). B. Triangular oral cavity. C. Single macronucleus. LF, left oral ciliary field; MA, macronucleus; RF, right oral ciliary field. Scale bars = 20 μm.

gun, Gyeongsangnam-do, Korea (N 35°4′8.2″, E 128° 13′47.1″) on 4 February 2019.

Diagnosis. Size 38–58 × 22–42 μm after protargol impregnation (n = 3). Body roughly inverted triangular; buccal field triangular shape; sharply curved paroral membrane. Single contractile vacuole centrally located below oral field. Single ellipsoidal macronucleus. 24–30 adoral membranelles. About 25 somatic kineties.

Distribution. Australia and Korea.

Remarks. The Korean population of *B. triquetrus* resembles the type population described by Foissner (1993) in most aspects except the number of somatic kineties (25 vs. 19 on average). *Bryometopus triquetrus* is also similar to *B. pseudochilodon* Kahl, 1932, but they mainly differ in the shape of oral field (triangular vs. ellipsoidal) (Foissner, 1993).

Voucher slides. Two slides with protargol-impregnated specimens were deposited at the Nakdonggang National Institute of Biological Resources (NNIBRPR11662, NNIBRPR11663).

Class Oligohymenophorea de Puytorac *et al*., 1974
Subclass Scuticociliatia Small, 1967
Order Pleuronematida Fauré-Fremiet in Corliss, 1956

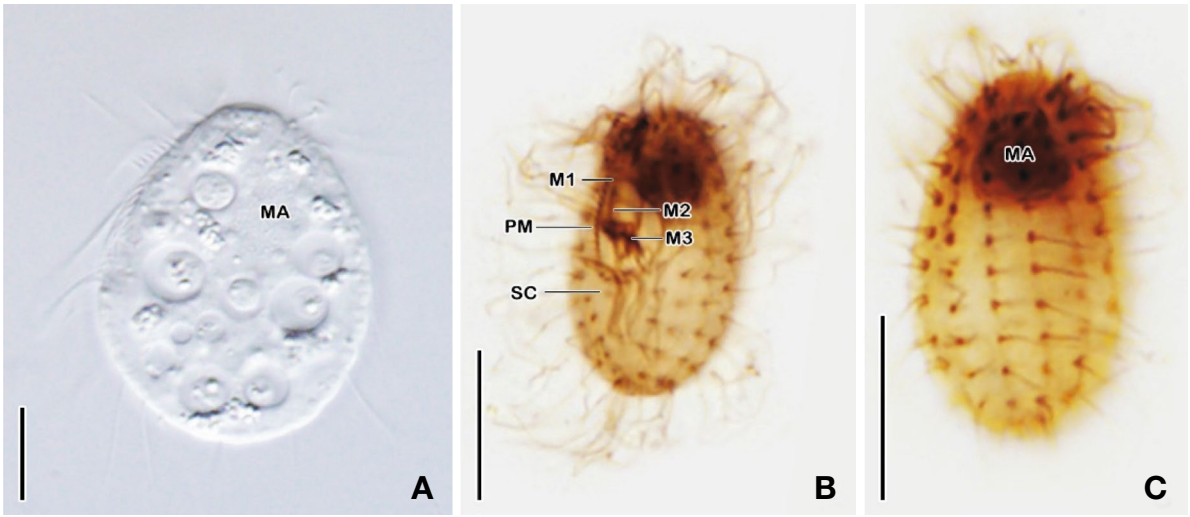

Fig. 16. *Cyclidium glaucoma* from life (A) and after protargol impregnation (B, C). A. Body shape in vivo. B. Details of oral ciliatures. C. Somatic ciliature on dorsal side. M1−3, membranelles; MA, macronucleus; PM, paroral membrane; SC, scutica. Scale bars = 10 μm.

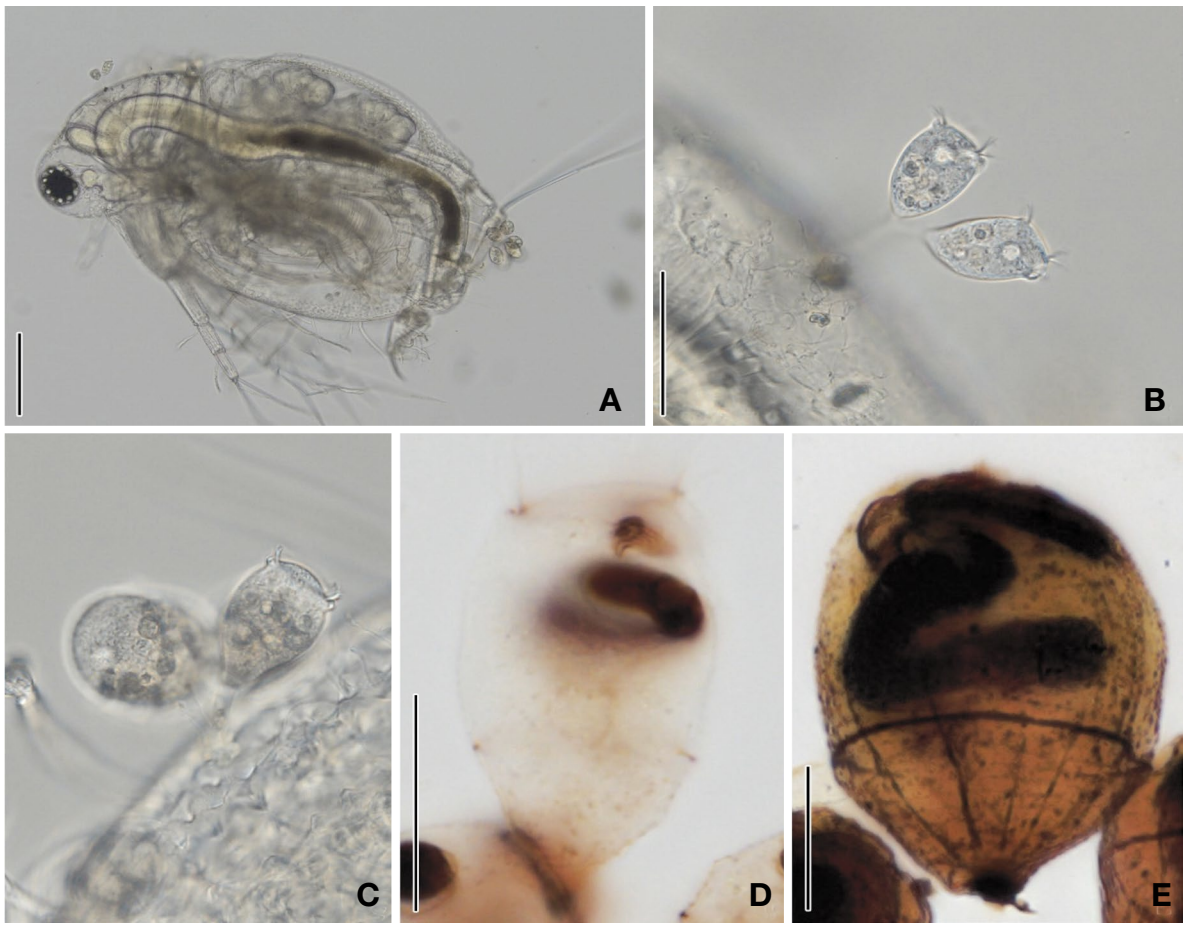

Fig. 17. *Epistylis pygmaeum* from life (A−C) and after protargol impregnation (D, E). A. Epibiotic habitat of *E. pygmaeum*. B. Body shape and contractile vacuole in vivo. C. Dichotomously branched stalk. D. Infundibular polykinety 1−3. E. Macronucleus and silverline systems. Scale bars = 200 μm (A); 50 μm (B); 20 μm (D); 10 μm (E).



Fig. 18. *Pseudovorticella vestita* from life (A), after protargol impregnation (B, C). A. Body shape in vivo to show pellicular vesicles. B. Two kinds of macronuclear pattern (globular type and longitudinal J-shaped type). C. Infundibular polykineties 1–3. MA, macronuclear nodules; P1–3, infundibular polykineties. Scale bar = 30 μm.

Family Cyclidiidae Ehrenberg, 1838
Genus *Cyclidium* Müller, 1773

16. *Cyclidium glaucoma* Müller, 1773 (Fig. 16)

Material examined. Terrestrial moss collected near Bongnae falls, Dodong-ri, Ulleung-eup, Ulleung-gun, Gyeongsangbuk-do, Korea (N 37°29′48.12″, E 130°53′29.64″) on 29 August 2018.
Diagnosis. Size in vivo about 20–30 × 10–15 μm (n = 3). Body ellipsoidal to fusiform with narrow anterior end with both sides convex and wide frontal plate. Cytoplasm colorless. One macronucleus and one micronucleus attached together in anterior half of cell. Contractile vacuole in posterior end of body. Somatic cilia about 8 μm long, caudal cilium up to 20 μm long; 10–12 ciliary rows, each with dikinetidal anterior half and monokinetidal posterior half.
Distribution. Cosmopolitan.
Remarks. The Korean population of *C. glaucoma* is very similar to the Antarctic population (Foissner *et al*., 1994; Foissner, 1996). However, they differ mainly in the body size (20–30 × 10–15 vs 11–22 × 8–11 μm). It differs from a German population by the ordinary spaced kinetids (vs. closely spaced few kinetids) in the posterior half of the somatic kinety 10 (Didier & Wilbert, 1981).
Voucher slides. Two slides with protargol-impregnated specimens were deposited at the Nakdonggang National Institute of Biological Resources (NNIBRPR11664, NNIBRPR11665).

Order Sessilida Kahl, 1933
Family Epistylididae Kahl, 1933
Genus *Epistylis* Ehrenberg, 1830

17. *Epistylis pygmaeum* (Ehrenberg, 1838) Foissner, Berger & Schaumburg, 1999 (Fig. 17)

Material examined. Freshwater with some debris collected from Domun-dong, Sangju-si, Gyeongsangbuk-do, Korea (N 36°26′8.09″, E 128°14′29.96″) on 14 May 2019.
Diagnosis. Colony dichotomously branching, usually short epistylid stalk; zooid size 35–40 × 21–27 μm in vivo; zooid shape barrel shape to cylindrical, rarely campanulate; peristomial lip width 21–22 μm in vivo (n = 3). Single contractile vacuole located on ventral side. Transverse silverlines, 16–23 striations between anterior end and aboral ciliary wreath, 11–15 striations between aboral ciliary wreath and scopula. Infundibular polykinety 3 composed of two rows.
Distribution. Cosmopolitan.
Remarks. *Epistylis pygmaeum* is a common epizoic peritrich. The Korean population of *E. pygmaeum* corresponds to other populations. *Epistylis pygmaeum* is similar to *E. anastatica*, but mainly differs in the size of zooid (35–40 μm vs. 60–100 μm) (Foissner *et al*., 1999).
Voucher slides. Two slides with protargol-impregnated specimens were deposited at the Nakdonggang National Institute of Biological Resources (NNIBRPR11672, NNIBRPR11673).

Family Vorticellidae Ehrenberg, 1838
Genus *Pseudovorticella* Foissner & Schiffmann, 1975

18. *Pseudovorticella vestita* (Stokes, 1883) Song & Wilbert, 1989 (Fig. 18)

Material examined. Brackish water (salinity 4.7‰) with some debris collected from Songji Lake, Injeong-ri, Jugwang-myeon, Goseong-gun, Gangwon-do, Korea (N 38°20′00.6″, E 128°30′47.6″) on 16 September 2019.
Diagnosis. Zooid size 65−80 × 45−60 μm in vivo; inverted bell-shaped; peristomial lip width about 65−85 μm in vivo (n = 3); contractile stalk; two types of macronucleus, longitudinally oriented J-shaped and small globular nodules scattered whole body. Ventrally located contractile vacuole. Conspicuous pellicular vesicles. Rectangular silverlines 15−18 striations between peristomial lip and trochal band, 7−9 striations between trochal band and scopula. Infundibular polykineties 1−3 each consists of three rows, polykinety 3 with shorter inner row and longer and diverged outer two rows.
Distribution. China, Germany, and Korea.
Remarks. The Korean population of *P. vestita* is similar to other populations except in the shape of the macronucleus (J-shaped and small globular nodules vs. only J-shaped) (Song and Wilbert, 1989). *Pseudovorticella vestita* is also similar to *P. chlamydophora* and differs mainly in the number of silverlines between anterior and trochal band (15−18 vs. 17−20) and between trochal band and scopula (7−9 vs. 14−17) (Song and Wilbert, 1989).
Voucher slides. Two slides with protargol-impregnated specimens were deposited at the Nakdonggang National Institute of Biological Resources (NNIBRPR11686, NNI BRPR11687).

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