

First Record of Six Marine Ciliate Species of Genus *Strombidium* (Ciliophora: Spirotricha: Oligotrichia) from Korea with Ecological Notes

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ABSTRACT

To supply the morphological and ecological information of oligotrich ciliates in Korea, water samples were seasonally collected in Gwangyang Bay and Jinhae Bay from August, 2010 to February, 2012 and processed by quantitative protargol staining method. As a result, six species belonging to the genus *Strombidium* Claparède and Lachmann, 1859 are identified: *Strombidium emergens* Kahl, 1932; *S. dalum* Lynn et al., 1988; *S. epidemum* Lynn et al., 1988; *S. tressum* Lynn et al., 1988; *S. bilobum* Lynn and Gilron, 1993; *S. pollostomum* Lynn and Gilron, 1993. These six species were newly reported from Korean coastal waters. *Strombidium emergens* is a middle sized *Strombidium* (20-50 µm in length) and has open and deep oral groove to girdle portion. *Strombidium dalum* is a small sized *Strombidium* (≤ 20 µm in length), that has torch-like spiral anterior membranelles and an inverted triangles-shaped macronucleus on the posterior pole. The small sized *S. epidemum* has conspicuous trichites surrounding the girdle portion and ventral membranelles distinctly separated from anterior membranelles. The small sized *S. tressum* has torch-like spiral and extremely long trichites among the cilia of anterior membranelles. The middle sized *S. bilobum* has a bilobed macronucleus. *Strombidium pollostomum* is also a small sized *Strombidium* but its ventral membranelles are continuously connected with anterior membranelles. The five species except *S. emergens* occurred frequently over the wide range of water temperatures and salinities.

Keywords: *Strombidium*, oligotrich ciliates, coastal waters, quantitative protargol staining, ecology, morphology

INTRODUCTION

In the marine ecosystem, ciliates have been recognized as a dominant group in microzooplankton and known to serve as an effective link between the microbial loop and metazoan food web (Maeda and Carey, 1985; Maeda, 1986; Agatha, 2011). Recent investigations show that aloricate oligotrich ciliates occur in high numbers and consume significant quantities of autotrophic and heterotrophic microbial production (Quevedo and Anadón, 2000; Fileman and Leakey, 2005; Bojanic et al., 2006). The oligotrichs have been recorded with Bütschli's classification scheme since 1889 and about 300 species have been reported (excluding tintinnids) up to the present (Agatha, 2004a; Agatha and Strüder-Kypke, 2007; Xu et al., 2009). However, the taxonomic composition and ecological characteristics of the oligotrichs in Korean coastal

waters are poorly known. To date, only 18 aloricate oligotrichs were described (only about 6% of recorded species in the world) (Suzuki and Han, 2000; Jeong et al., 2004; Moon et al., 2004; Kim et al., 2005, 2008, 2010; Ma and Choi, 2005; Lee et al., 2006, 2011).

The genus *Strombidium* Claparède and Lachmann, 1859 has well known as a cosmopolitan and diverse group within the oligotrichs. The characteristics of these species are as follows: anterior membranelles and ventral membranelles encircled on the oral region and not forming a complete circle, polysaccharide plates (or platelets) covered posterior half of body, horizontal girdle kinety and longitudinal ventral kinety, trichites forming a characteristic band. About 80 species have been described up to now, but many species still need to be studied due to the lack of morphologic information that can be used to identify the species (Fauré-Fremiet, 1932; Kahl,

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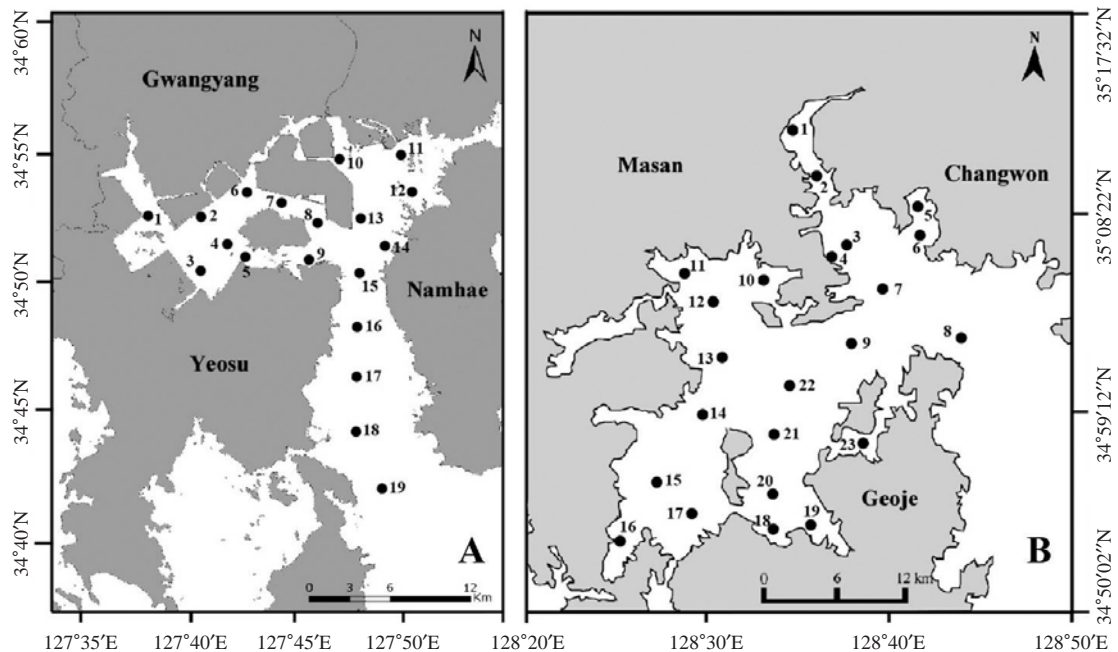


Fig. 1. Sampling sites from Gwangyang Bay (A, 19 sites) and Jinhae Bay (B, 23 sites) in the southern coastal areas of Korea.

1932; Maeda and Carey, 1985; Lynn et al., 1988; Montagnes et al., 1988, 1990, 2002; Montagnes and Lynn, 1991; Petz and Foissner, 1992; Lynn and Gilron, 1993; Martin and Montagnes, 1993; Petz et al., 1995; Agatha and Riedel-Lorjé, 1997; Kim and Taniguchi, 1997; Montagnes and Humphrey, 1998; Song and Bradbury, 1998; Lei et al., 1999; Song et al., 2000; Agatha, 2003; Granda and Montagnes, 2003; Modeo et al., 2003; Agatha, 2004b; Agatha et al., 2005; Xu et al., 2006, 2007, 2009; McManus et al., 2010; Liu et al., 2011). Several studies have described with their ecological data concerning the occurrences at different water temperatures and salinities, as well as the morphologic data. According to their studies, *Strombidium antarcticum* occurred in water temperature of up to -4.5°C and salinity of up to 60 psu (practical salinity units). *Strombidium conicum* was recorded that the abundance is up to 123,600 cells per liter within the range of water temperatures of $4-12^{\circ}\text{C}$ and salinities of 12-24 psu. The maximum abundance of *Strombidium lingulum* forming the red-tide was recorded up to 1.5×10^6 cells per liter with a water temperature of 14°C and salinity of 31-32 psu (Petz et al., 1995; Agatha and Riedel-Lorjé, 1997; Montagnes and Humphrey, 1998).

As a serial report on the taxonomical study of oligotrich ciliates in Korean coastal waters, we describe morphologically six *Strombidium* species collected from Gwangyang Bay and Jinhae Bay in the southern coastal area and provide also the ecological data of these species.

MATERIALS AND METHODS

Water sampling

Ciliate plankton was investigated seasonally in Gwangyang Bay (19 sites in Fig. 1A) and Jinhae Bay (23 sites in Fig. 1B) from August 2010 to February 2012 (August and November in 2010; February, May, August, and November in 2011; February in 2012). To collect ciliate cells, surface sea water was sampled by a bucket and fixed using Bouin's solution in the field (at final concentration 10%, v/v). Water temperature and salinity were measured *in situ* using electronic conductivity-temperature-depth sensor (IDRONUT Ocean Seven 316; IDRONUT, Brugherio, Italy).

Cell identification and counting

The water samples fixed were analyzed by the quantitative protargol stain (QPS), following the protocol of Montagnes and Lynn (1993). In brief, 50 mL of fixed water samples were filtered through $0.8 \mu\text{m}$ in pore size membrane filters (Startorius Stedin Biotech, Goettingen, Germany) and filtered samples were covered with a thin layer of agar to avoid the loss of cells during the next step of preparation. Then, the membranes were bleached, protargol impregnated and mounted. Under a light-field microscope (Zeiss Axioskop II; Carl Zeiss, Jena, Germany), the protargol impregnated cells were identified and counted at the magnification of $400-1,600 \times$.

Terminology

The terminology and classification for the ciliate taxonomy are according to Montagnes and Lynn (1991) and Agatha (2004a) respectively.

RESULTS AND DISCUSSION

Class Oligotrichea Bütschli, 1889

Subclass Oligotrichia Bütschli, 1889

Order Oligotrichida Bütschli, 1889

Family Strombidiidae Fauré-Fremiet, 1970

¹*Genus *Strombidium* Claparède and Lachmann, 1859

²**Strombidium emergens* (Leegaard, 1915) Kahl, 1932
(Table 1, Figs. 2, 3)

Strombidium sulcatum Kahl, 1932: 503, fig. 13; Pettigrosso, 2003: 123, fig. 10.

Strombidium sulcatum Lynn et al., 1988: 273, figs. 4E, 6J.

Strombidium ventropinnum Martin and Montagnes, 1993: 541, figs. 7A-E, 8A, B.

Diagnosis. Body long cone-shaped; deep and open oral groove on ventral surface, extending posteriorly to about halfway down the cell; size 22-27 μm in length and 11-17 μm in width after protargol impregnation; anterior membranelles composed of 13-15 polykinetids; ventral membranelles distinctly separated from anterior membranelles, composed of 8-9 polykinetids; girdle kinety completely surrounding the cell, composed of 34-42 dikinetids; ventral kinety composed of 9-11 dikinetids; one heart-shaped macronucleus, 6 \times 5 μm in size; one spherical micronucleus, 1-2 μm in diameter.

Morphological description of the Korean population.

Long cone-shaped body, cylindrical anterior portion and conical posterior portion, no apical protrusion detected. Numerous trichites inserting above girdle and extending to posterior of body, not in bundles (Fig. 2F). Distended cell surface covered from girdle to posterior pole of the cell. No polygonal surface recognizable in protargol impregnated specimen (Fig. 2C-E). Size 22-27 μm in length and 11-17 μm in width after protargol impregnation (average 24.5 \times 14.1 μm , n=12).

Oral groove relatively deep and open on ventral surface, extending to about halfway down the cell (2/5-1/2 of the body). Anterior membranelles distinctly separated from ventral membranelles. Bases of anterior membranelles connected by fibres system, the cilia of anterior membranelles torch-like spiral, composed of 13-15 polykinetids (average 14 polykinetids, n=12). Ventral membranelles lying on the left wall

of oral groove that forms a sunken pit, composed of 8-9 polykinetids (average 9 polykinetids, n=12). No endoral membrane detected (Fig. 2A-C).

Somatic ciliature composed of girdle kinety and ventral kinety, no extra kinety detected. Girdle kinety, horizontal and equatorial, completely surrounding the cell and composed of 34-42 dikinetids (average 38 dikinetids, n=7). Ventral ventral kinety, slightly tilted toward the right, composed of 9-11 dikinetids (average 10 dikinetids, n=2).

One macronucleus, heart-shaped, located below oral groove and contained many spherical nucleoli, 4-8 μm in length and 4-6 μm in broad width (average 6.2 \times 5.1 μm , n=12). One micronucleus attached on macronucleus, 1-2 μm in diameter.

Occurrence and ecological characteristics. The Korean population was collected from Jinhae Bay (August, 2011) and Gwangyang Bay (November, 2011) recording the water temperatures of 22-23°C and 15°C and the salinities of 27-28 psu and 31 psu respectively. A maximum abundance (700 cells/L) was observed in August, 2011 from Jinhae Bay (Fig. 3).

The Argentina population was collected from Puerto Cuatros where the water temperature and salinity were 9-12°C and 30-33 psu respectively (Pettigrosso, 2003).

Comparison with other populations. *Strombidium emergens* was recorded by Leegaard (1915), Kahl (1932), Lynn et al. (1988), Petz et al. (1995), and Pettigrosso (2003). Leegaard (1915) first described this species as *Laboea emergens*. Unfortunately, the morphological informations described by Leegaard (1915) and Kahl (1932) were not enough to identify *S. emergens*.

This population is similar to *Strombidium sulcatum* which was recorded from Isles of Shoals (Gulf of Maine, Atlantic population) by Lynn et al. (1988), but the species was transferred to *S. emergens* by Montagnes et al. (1990). More recently, Pettigrosso also recorded the Argentinian population of *S. emergens*. These three populations—Korean, Argentinian and Atlantic populations—have almost overlapped morphometric data except for the shape of macronucleus.

Compared with the Antarctic population described by Petz et al. (1995), the two populations have many differences; the cell size is considerably smaller (22-27 \times 11-17 μm in the Korean population vs. 90 \times 49-52 μm in the Antarctica population), a smaller number of ventral kinety (9-11 dikinetids vs. 20 dikinetids), and more ventral membranelles (8-9 polykinetids vs. 4-5 polykinetids). As well, the ventral membranelles of the Antarctica population is inconspicuous (vs. extending to girdle portion in the Korea population), continuous with anterior membranelles (vs. conspicuously separated from anterior membranelles in the Korean population),

Korean name: ¹*민소모충속, ²*반나민소모충

Table 1. Morphometrical characterization of *Strombidium emergens* (S.em), *S. dalum* (S.d.), *S. epidemum* (S.ep.), *S. tressum* (S.t.), *S. bilobum* (S.b.), *S. pollostomum* (S.p.)

Characteristics	Species	Min	Max	Mean	SD	SE	CV	N
Cell length	S.em.	21.5	27.1	24.5	1.9	0.6	7.8	12
	S.d.	12.5	18.8	14.9	1.7	0.5	11.3	14
	S.ep.	12.2	20.4	14.6	2.1	0.5	14.2	17
	S.t.	12.6	21.3	15.1	2.2	0.5	14.7	22
	S.b.	30.9	36.3	33.3	1.6	0.4	4.8	15
Cell width	S.p.	11.6	19.1	15.1	2.4	0.5	15.8	22
	S.em.	10.9	16.9	14.1	1.6	0.5	11.4	12
	S.d.	7.0	10.2	9.2	0.9	0.3	10.2	14
	S.ep.	10.1	16.7	12.0	1.5	0.4	12.9	17
	S.t.	9.9	15.0	12.4	1.4	0.3	11.3	22
Cell length : width, ratio	S.b.	14.2	20.6	17.8	2.1	0.6	12.1	15
	S.p.	7.5	14.5	10.7	1.8	0.4	16.7	22
	S.em.	1.5	2.1	1.8	0.2	0.1	10.4	12
	S.d.	1.4	2.2	1.6	0.3	0.1	15.3	14
	S.ep.	1.1	1.3	1.2	0.1	0.0	5.2	17
Oral width	S.t.	1.1	1.4	1.2	0.1	0.0	7.1	22
	S.b.	1.7	2.7	2.0	0.3	0.1	16.2	15
	S.p.	1.1	1.7	1.4	0.1	0.0	8.5	22
	S.b.	19.4	23.8	22.2	2.4	1.4	11.0	3
	S.em.	9.2	12.8	11.3	0.9	0.3	8.3	12
Oral groove length	S.b.	12.4	22.6	16.6	2.6	0.7	15.5	15
GK width	S.p.	8.3	10.2	9.3	0.7	0.3	7.2	6
Cell length : GK width, ratio	S.b.	1.5	2.7	2.0	0.3	0.1	15.7	15
AM, number	S.em.	13.0	15.0	13.8	0.7	0.2	5.0	12
	S.d.	13.0	15.0	14.0	0.7	0.2	4.9	14
	S.ep.	12.0	15.0	13.2	1.0	0.2	7.3	17
	S.t.	13.0	15.0	14.1	0.9	0.2	6.5	22
	S.b.	14.0	17.0	14.8	1.0	0.3	6.6	11
VM, number	S.p.	12.0	16.0	13.6	1.0	0.2	7.5	19
	S.em.	8.0	9.0	8.2	0.4	0.1	4.8	12
	S.d.	6.0	9.0	7.3	1.1	0.3	14.6	12
	S.ep.	5.0	7.0	5.9	0.5	0.1	8.2	17
	S.t.	5.0	8.0	6.4	0.7	0.2	10.9	18
GK, number	S.b.	9.0	13.0	10.5	1.4	0.5	13.5	8
	S.p.	4.0	6.0	5.3	0.7	0.2	14.1	19
	S.em.	34.0	42.0	3.8	2.8	1.1	7.4	7
	S.d.	20.0	24.0	22.0	1.6	0.8	7.4	4
	S.t.	30.0	38.0	33.0	3.3	1.3	10.0	6
VK, number	S.b.	36.0	40.0	38.0	2.0	1.2	5.3	3
	S.p.	14.0	16.0	15.0	1.4	1.0	9.4	2
	S.em.	9.0	11.0	10.0	1.4	1.0	14.1	2
	S.d.	4.0	7.0	5.2	1.3	0.6	25.1	5
	S.ep.	4.0	4.0	4.0	-	-	-	1
Ma, number	S.t.	8.0	11.0	8.8	0.9	0.3	9.9	11
	S.b.	4.0	6.0	4.8	0.8	0.3	17.4	9
	S.p.	3.0	5.0	3.9	0.6	0.2	16.5	8
	S.em.	1.0	1.0	1.0	0.0	0.0	0.0	12
	S.d.	1.0	1.0	1.0	0.0	0.0	0.0	12
Ma, length1	S.ep.	1.0	1.0	1.0	0.0	0.0	0.0	17
	S.t.	1.0	1.0	1.0	0.0	0.0	0.0	11
	S.b.	2.0	2.0	2.0	0.0	0.0	0.0	15
	S.p.	1.0	1.0	1.0	0.0	0.0	0.0	20
	S.em.	4.4	7.6	6.2	0.8	0.2	13.0	12
Ma, length2	S.d.	3.5	6.0	4.7	0.7	0.2	14.2	12
	S.ep.	4.3	11.1	6.1	1.8	0.4	28.6	17
	S.t.	5.1	7.3	6.0	0.6	0.1	9.9	21
	S.b.	6.0	11.1	8.8	1.2	0.3	13.6	14
	S.p.	4.1	8.7	6.0	1.4	0.3	22.9	20
S.b.	6.5	10.6	8.0	1.2	0.3	15.2	13	

Table 1. Continued

Characteristics	Species	Min	Max	Mean	SD	SE	CV	N
Ma, width1	S.em.	4.2	5.8	5.1	0.5	0.1	8.9	12
	S.d.	2.2	4.5	3.6	0.7	0.2	19.4	12
	S.ep.	3.4	6.2	4.2	0.8	0.2	18.4	17
	S.t.	1.3	6.0	4.6	1.0	0.2	22.4	21
	S.b.	3.6	7.9	4.9	1.1	0.3	21.7	14
	S.p.	3.4	7.3	4.9	1.2	0.3	25.4	20
Ma, width2	S.b.	3.5	7.4	5.0	1.2	0.3	24.5	13
Mi, number	S.em.	1.0	1.0	1.0	0.0	0.0	0.0	4
	S.d.	1.0	1.0	1.0	0.0	0.0	0.0	6
	S.ep.	1.0	1.0	1.0	0.0	0.0	0.0	7
	S.t.	1.0	1.0	1.0	0.0	0.0	0.0	4
	S.p.	1.0	1.0	1.0	0.0	0.0	0.0	5
Mi, diameter	S.em.	1.1	2.0	1.5	0.4	0.2	26.1	4
	S.d.	0.9	1.8	1.3	0.3	0.1	24.6	6
	S.ep.	0.9	1.8	1.3	0.4	0.1	31.4	7
	S.t.	0.8	1.5	1.0	0.3	0.2	30.0	4
	S.p.	1.0	1.3	1.1	0.1	0.1	10.8	5
A globular drop, diameter	S.d.	1.0	1.3	1.1	0.2	0.1	14.1	3
	S.ep.	1.1	2.1	1.4	0.3	0.1	18.9	10
	S.p.	0.9	1.2	1.1	0.1	0.0	10.4	10
Oral to posterior, length	S.em.	9.9	15.5	13.2	1.9	0.6	14.6	12
	S.d.	6.4	12.6	9.1	1.7	0.5	18.8	14
	S.ep.	6.4	10.1	7.9	0.9	0.2	12.0	15
	S.t.	7.6	12.9	10.1	1.7	0.4	16.4	20
	S.b.	20.8	26.6	23.8	1.6	0.4	6.8	15
	S.p.	6.6	13.1	10.0	2.1	0.5	20.5	18
GK to posterior, length	S.b.	12.2	15.3	13.2	1.0	0.3	7.4	11
	S.p.	5.3	6.8	6.1	1.0	0.7	16.7	2
T, length	S.ep.	2.1	7.4	3.7	1.6	0.6	43.0	8

Data based on protargol impregnated and randomly selected specimens. Measurements in μm .

Min, minimum; Max, maximum; Mean, arithmetic mean; SD, standard deviation; SE, standard error; CV, coefficient of variation; N, number of specimen; AM, anterior membranelles; VM, ventral membranelles; GK, girdle kinety; VK, ventral kinety; Ma, macronucleus; Mi, micronucleus; T, trichites.

and covered by cytoplasmic wall (vs. open on ventral side).

Strombidium ventropinum recorded as a new species by Martin and Montagnes (1993) is also very similar to this population. However, *S. ventropinum* has more dikinetids of ventral kinety (10-14 vs. 9-11 in the Korean population of *S. emergens*) and one ovoid macronucleus (vs. heart-shaped). Morphologically, the Korean population is more similar to *S. ventropinum* rather than the Antarctica population of *S. emergens* in protargol impregnation.

¹**Strombidium dalum* Lynn, Montagnes and Small, 1988 (Table 1, Figs. 4, 5)

Strombidium dalum Lynn et al., 1988: 265, figs. 3A, 5F; Lynn and Gilron, 1993: 62, figs. 2C, 7C; Pettigrosso, 2003: 124, fig. 11; Suzuki and Ota, 2011: 150, figs. 13, 14.

Diagnosis. Body conical to rhombus-shaped; deep oral groove; prominent and numerous trichites, positioned above girdle portion; size 13-19 μm in length and 7-10 μm in width

after protargol impregnation; anterior membranelles composed of 13-15 dikinetids; ventral membranelles distinctly separated from anterior membranelles, composed of 6-9 dikinetids; equatorial girdle kinety completely surrounding the cell, composed of 20-24 dikinetids; vertical ventral membranelles composed of 4-7 dikinetids; one inverted triangle-shaped macronucleus located at posterior of cell, $5 \times 4 \mu\text{m}$ in size.

Morphological description of the Korean population.

Body mostly conical to rhombus-shaped, long conical shape from several cells observed (Fig. 4D, E), truncated anterior portion and narrowed posterior portion, no apical protrusion detected (Fig. 4A-C). Small lip on anterior pole of ventral side (Fig. 4I). Trichites, prominent and numerous, but not in bundles, completely surrounding the girdle portion (Fig. 4H, I). Slightly inflated distended cell surface from girdle portion to posterior end, no polygonal cell surface recognizable in protargol impregnated specimen. Size 13-19 μm in length and 7-10 μm in width after protargol impregnation (average $14.9 \times 9.2 \mu\text{m}$, $n=14$). Cell length by width ratio, 1.4-2.2 : 1

Korean name: ¹*햇불민소모충

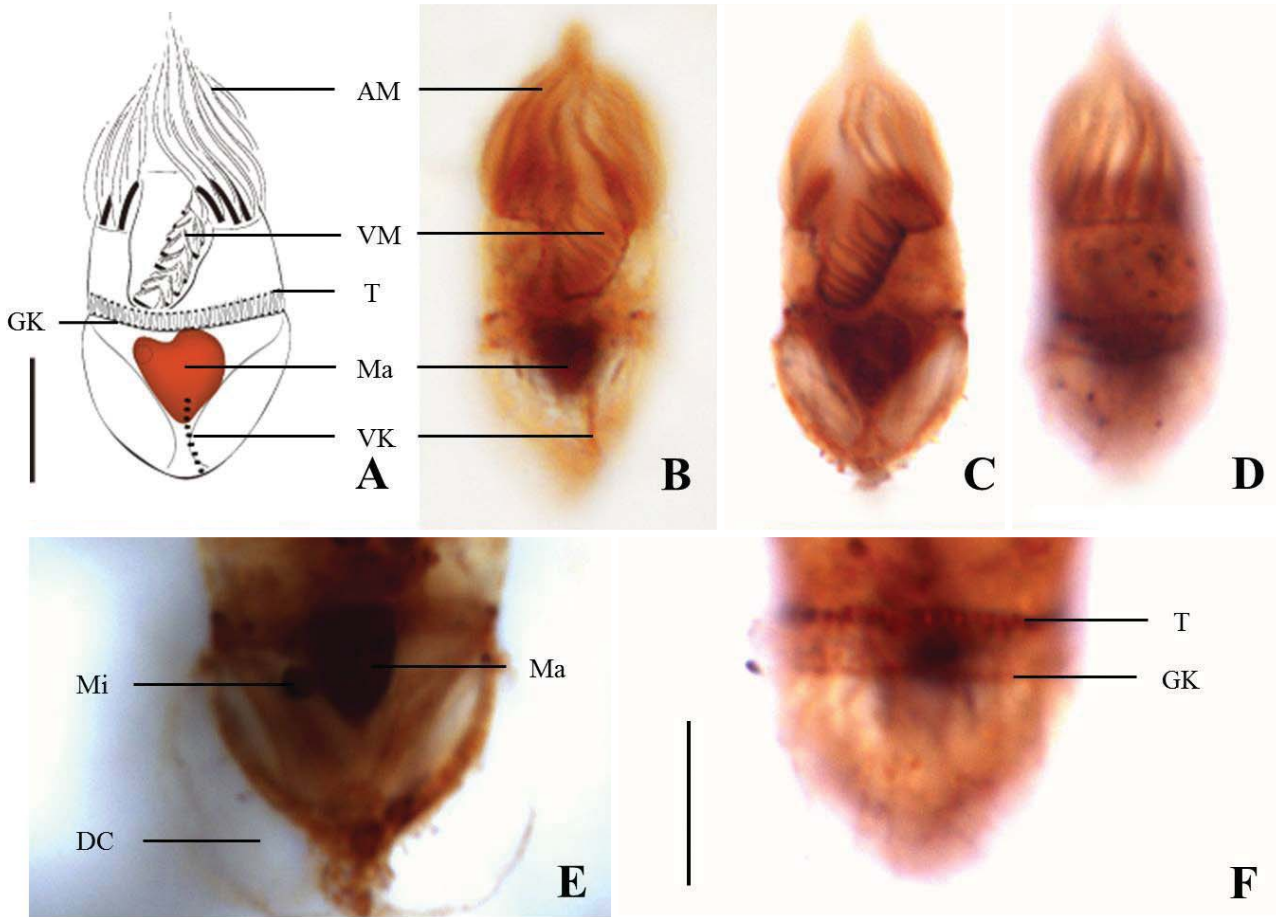


Fig. 2. *Strombidium emergens* after protargol impregnation. A-C, Ventral view; D, Doral view; E, One macronucleus and one micronucleus; F, Trichites positioned above girdle kinety. AM, anterior membranelles; DC, distended cell surface; GK, girdle kinety; Ma, macronucleus; Mi, micronucleus; T, trichites; VK, ventral kinety; VM, ventral membranelles. Scale bars: A, F=10 μ m.

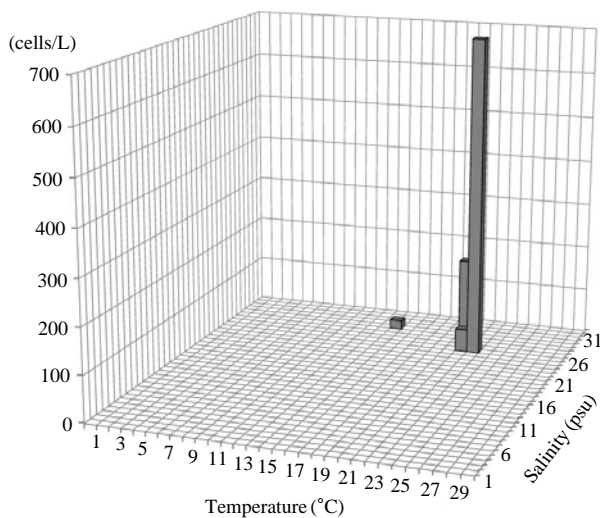


Fig. 3. Abundances of *Strombidium emergens* occurred at different temperatures ($^{\circ}$ C) and salinities (psu).

(average 1.6 : 1, n=14).

Anterior membranelles distinctly separated from ventral membranelles. The cilia of anterior membranelles, long and spiral (usually torch-like shaped cilia), surrounding the anterior end of cell, composed of 13-15 polykinetids (average 14 polykinetids, n=14). Ventral membranelles lying on deep oral groove that forms a sunken pit, almost enclosed by left wall of oral groove, extending obliquely towards right side of cell and terminating one-third to half of the way down the cell, composed of 6-9 polykinetids (average 8 polykinetids, n=12). No endoral membrane detected.

Somatic ciliature composed of girdle kinety and ventral kinety, no extra kinety detected. Girdle kinety, equatorial, completely surrounding, composed of 20-24 dikinetids (average 22 dikinetids, n=4). Ventral kinety, vertically extended from posterior of cell, composed of 4-7 dikinetids (average 6 dikinetids, n=5) (Fig. 4C, E).

One macronucleus, mostly inverted triangle shaped and

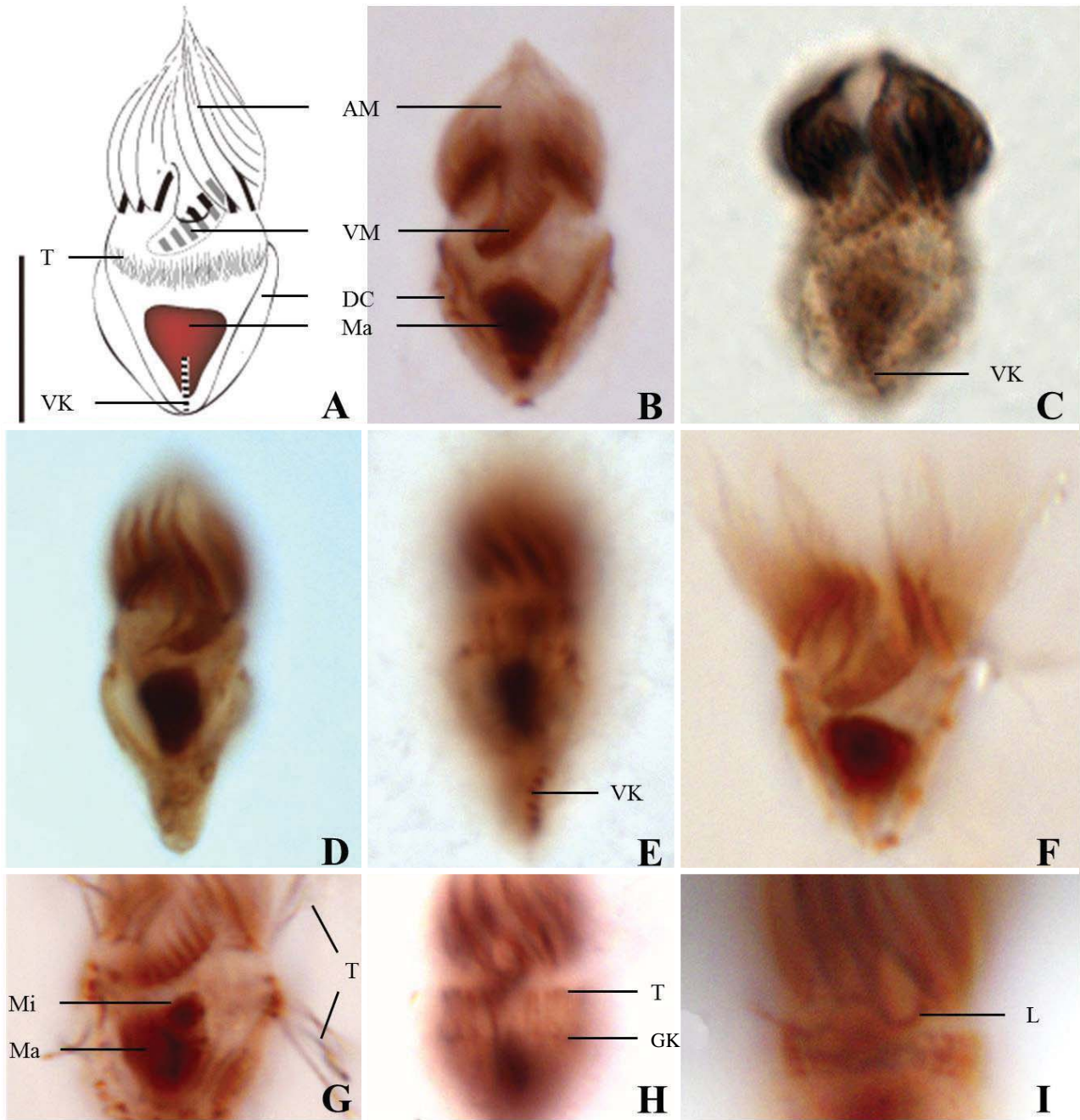


Fig. 4. *Strobilidim dalum* after protargol impregnation. A-I, Ventral view; D, Several cells having long body shape; F, Not spiral cilia of anterior membranles; G, Extruded trichites from the body; H, Trichites positioned above girdle kinety; I, Small lip on oral region. AM, anterior membranles; DC, distended cell surface; GK, girdle kinety; L, small lip; Ma, macronucleus; Mi, micronucleus; T, trichites; VK, ventral kinety; VM, ventral membranles. Sale bar: A=10 μ m.

located at posterior end, 4-6 μ m in length and 2-5 μ m in maximum width (average 4.7 \times 3.6 μ m, n=12). One spherical micronucleus, 1-2 μ m in diameter (average 1.3 μ m in diameter, n=6) (Fig. 4G).

Occurrence and ecological characteristics. The Korean

population was collected from Jinhae Bay and Gwangyang Bay in all seasons (water temperature of 4-29°C and salinity of 9-34 psu). A maximum abundance (1,800 cells/L) was observed in Jinhae Bay in August, 2011 (water temperature of 22°C and salinity of 27 psu) (Fig. 5).

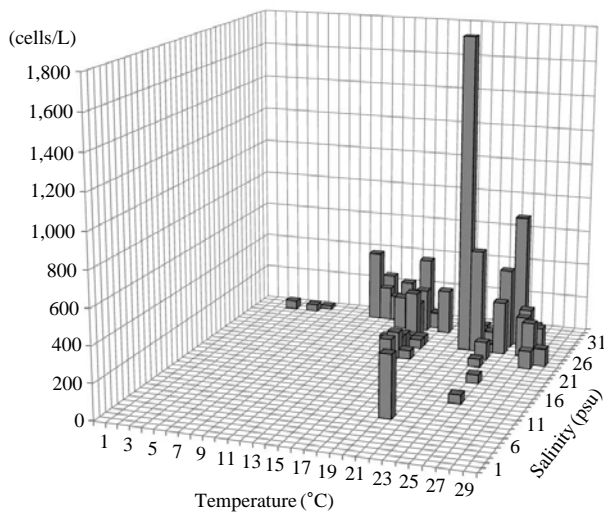


Fig. 5. Abundances of *Strombidium dalum* occurred at different temperatures (°C) and salinities (psu).

The Argentina population was collected from Puerto Cuatros in the lower temperature of 9–13°C and the salinity of 30–31 psu (Pettigrosso, 2003).

Comparison with other populations. According to original description by Lynn et al. (1988), the cilia of the anterior polykinetids in the Atlantic population have spiral torch-like anterior membranelles. Lynn and Gilron (1993) noted that it may be an artifact of fixing and staining. They observed both torch-like cilia of anterior membranelles and fan-like one from the Jamaican population. In the Korean population, we also observed the two types of anterior membranelles (Fig. 4F). There are no description of the ventral kinety in the Atlantic and the Argentina populations (Lynn et al., 1988; Lynn and Gilron, 1993). However, the Jamaica and the Korean populations appeared the ventral kinety (3 dikinetids and 4–7 dikinetids respectively) (Pettigrosso, 2003). Recently, the Canadian population was recorded by Suzuki and Ota (2011). Compared with the Korean population, all morphometric data overlap except for macronucleus size (about $5 \times 4 \mu\text{m}$ in the Korean population vs. $8 \times 6 \mu\text{m}$ in the Canadian population).

¹**Strombidium epidemum* Lynn et al., 1988 (Table 1, Figs. 6, 7)

Strombidium epidemum Lynn et al., 1988: 267, figs. 3B, 6A, B; Lynn and Gilron, 1993: 62, figs. 5A, 7A, B; Suzuki and Ota, 2011: 151, figs. 15, 16.

Diagnosis. Body truncate conical; size 12–20 μm in length

and 10–17 μm in width after protargol impregnation; prominent trichites surrounding the cell; oral groove opened on ventral surface; anterior membranelles composed of 12–15 dikinetids; ventral membranelles separated from anterior membranelles, composed of 5–7 dikinetids; equatorial girdle kinety, surrounding the cell; one spherical to ovoid macronucleus, $6 \times 4 \mu\text{m}$ in size; small *Strombidium* species ($\leq 20 \mu\text{m}$).

Morphological description of the Korean population.

Body truncate conical. Size 12–20 μm in length and 10–17 μm in width (average $14.6 \times 12.0 \mu\text{m}$, $n=17$), cell length by width ratio, 1.2 : 1.0 after protargol impregnation. Prominent trichites inserting to anterior of girdle portion and extending internally toward posterior of body, 2–7 μm in length. A tiny globular drop on posterior end of cell, 1–2 μm in diameter (average 1.4 μm in diameter, $n=10$) (Fig. 6A, B).

Oral groove fairly opened on ventral surface of the cell. Anterior membranelles, equal length surrounding anterior end, composed of 12–15 polykinetids (average 14 polykinetids, $n=17$). Ventral membranelles are distinctly separated from anterior membranelles and lie on a oral groove which occupies 1/2 of cell length, to the posterior of ventral membranelles to posterior pole of cell distance 6–10 μm (average 7.9 μm , $n=15$), composed of 5–7 polykinetids (average 6 polykinetids, $n=17$) (Figs. 6B, 12F). One to two polykinetids of ventral membranelles lying into oral cavity. No endoral membrane detected.

Somatic ciliature composed of girdle kinety and ventral kinetids, no extra kinety detected. Girdle kinety, equatorial, completely surrounding cell. Vertical ventral kinety with 4 dikinetids from posterior end of body.

One spherical to ovoid macronucleus, $4\text{--}11 \times 3\text{--}6 \mu\text{m}$ (average $6.1 \times 4.2 \mu\text{m}$, $n=17$), positioned posterior. One micronucleus on macronucleus, 1–2 μm in diameter (average 1.3 μm in diameter, $n=7$).

Opisthe (daughter cell) developing on right side of proter (Fig. 6C).

Occurrence and ecological characteristics. This species occurred from Jinhae Bay and Gwangyang Bay in all seasons (water temperature of 4–30°C and salinity of 2–34 psu). A maximum abundance (2,075 cells/L) of this species was observed in Jinhae Bay on May, 2011 (water temperature of 27°C and salinity of 27 psu) (Fig. 7).

Comparison with other populations. *Strombidium epidemum* was recorded from Gulf of Maine in 1988, Jamaica in 1993, and Canada in 2011 (not including ecological data). The Korean population is very similar to the Jamaican and the Canadian population in shape, body size, polykinetids number of anterior membranelles and ventral membranel-

Korean name: ¹*범소민소모충 (epidemos, Gr.-prevalent, 일반적인, 널리 퍼져있는)

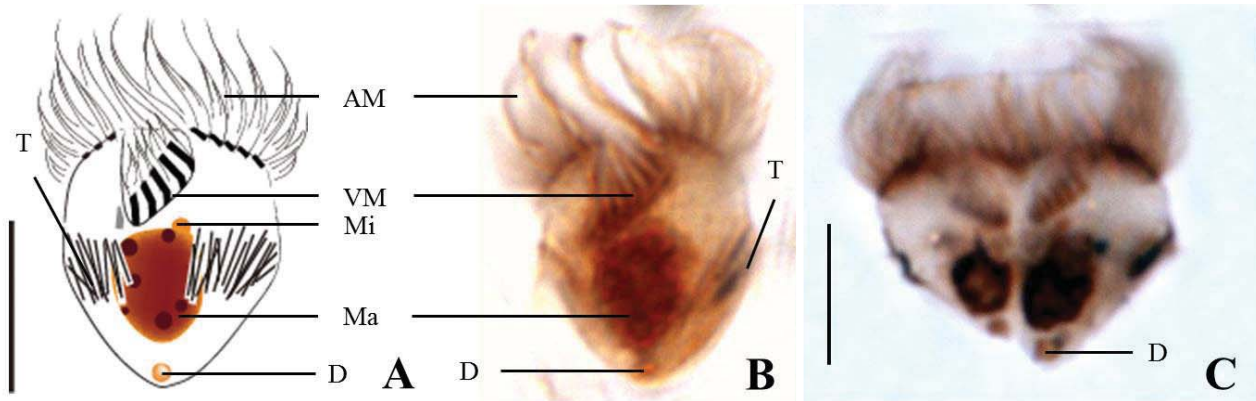


Fig. 6. *Strobilidium epidemum* after protargol impregnation. A, B, Ventral view; C, Division of *S. epidemum*. AM, anterior membranelles; Ma, macronucleus; Mi, micronucleus; D, a tiny globular drop at posterior end; T, trichites; VM, ventral membranelles. Sale bars: A, C=10 μ m.

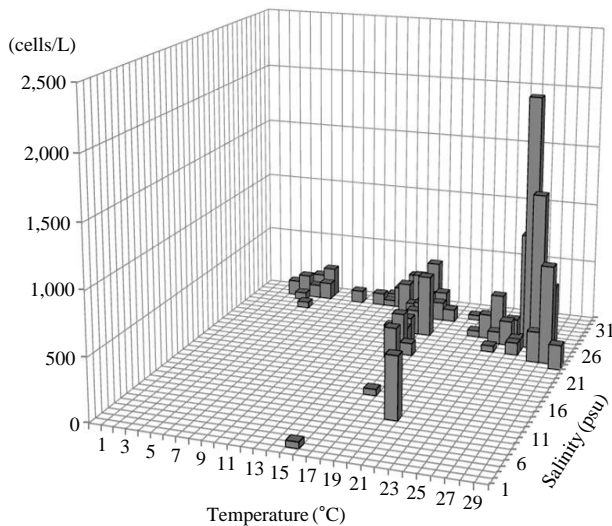


Fig. 7. Abundances of *Strobilidium epidemum* occurred at different temperatures ($^{\circ}$ C) and salinities (psu).

les, and ventral membranelles separated from anterior membranelles. However the Atlantic population has slightly smaller cell size than the Korean population (9-14 μ m in length vs. 12-20 μ m in length) (Lynn et al., 1988; Lynn and Gilron, 1993; Suzuki and Ota, 2011).

A tiny globular drop was positioned in the posterior end of *S. epidemum* cells collected from the bays in Korea. *Strobilidium dalum* and *S. pollostomum* described as Korean populations in this study were also included the drop. Further observations need to understand its function and position inside the cell.

¹*Strobilidium tressum* Lynn et al., 1988 (Table 1, Figs. 8, 9)

Strobilidium tressum Lynn et al., 1988: 274, figs. 4F, 6H, I.

Diagnosis. Body ovoid to ellipsoidal; size 13-21 μ m in length and 10-15 μ m in width after protargol impregnation; long trichites among cilia of anterior membranelles; long and torch-like spiral anterior membranelles composed of 13-15 polykinetids; ventral membranelles composed of 5-8 polykinetids; supraequatorial girdle kinety composed of 30-38 dikinetids; vertical ventral kinety composed of 8-11 dikinetids; one ovoid macronucleus, 6 \times 4 μ m in size; one spherical micronucleus, about 1 μ m in diameter.

Morphological description of the Korean population.

Body ovoid to ellipsoidal, relatively inflated distended cell surface from girdle portion to posterior pole, apical protrusion not found (Fig. 8A-C). Size 13-21 μ m in length and 10-15 μ m in width (average 15.1 \times 12.4 μ m, n=22). Trichites locating above girdle kinety, but not extending internally toward posterior of body (Fig. 8E). The long trichites among cilia of anterior membranelles, spirally extending over full length of cell (Fig. 8B, D, E).

Anterior membranelles, as long as almost body length, spirally twisted cilia (torch-like), completely surrounding the cell, and composed of 13-15 polykinetids (average 15 polykinetids, n=22). Ventral membranelles enclosed by the ring of anterior membranelles, composed of 5-8 polykinetids (average 7 polykinetids, n=18) (Fig. 8B, C).

Somatic ciliature composed of girdle kinety and ventral kinety, no extra kinety detected. Girdle kinety, supraequatorial, completely surrounding the cell, composed of 30-38 dikinetids (average 33 dikinetids, n=6). Ventral kinety slight-

Korean name: ¹*긴털민소모충

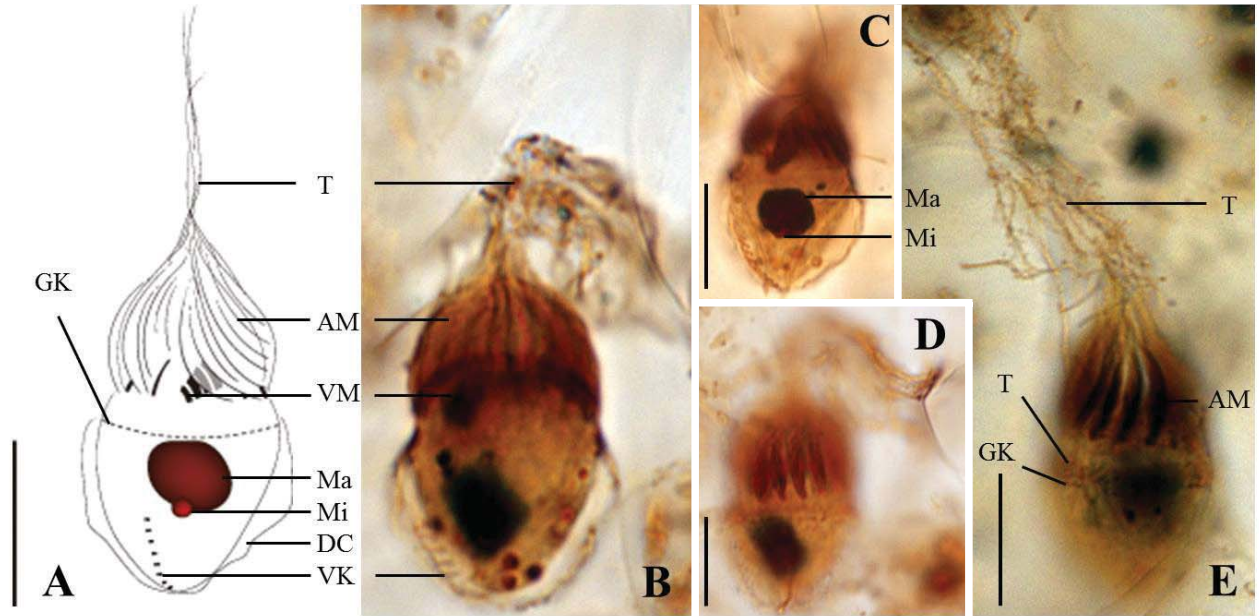


Fig. 8. *Strombidium tressum* after protargol impregnation. A-C, Ventral view; B, D, E, Long trichites among cilia of anterior membranelles. AM, anterior membranelles; DC, distended cell surface; GK, girdle kinety; Ma, macronucleus; Mi, micronucleus; T, trichites; VK, ventral kinety; VM, ventral membranelles. Scale bars: A, C-E=10 μ m.

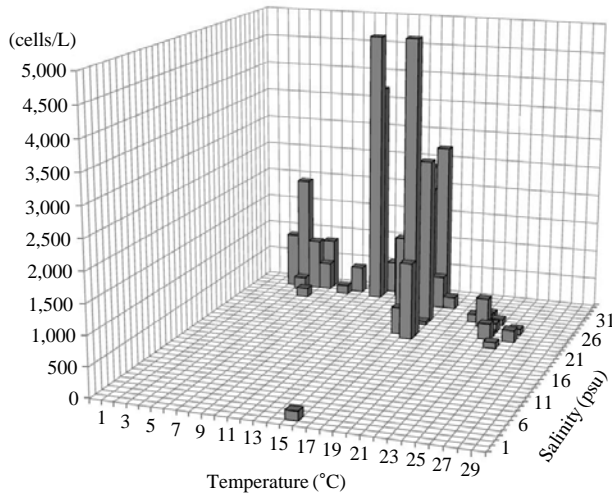


Fig. 9. Abundances of *Strombidium tressum* occurred at different temperatures ($^{\circ}$ C) and salinities (psu).

ly slanted toward left, composed of 8-11 dikinetids on distended cell surface (average 9 dikinetids, $n=11$) (Fig. 8B).

One ovoid macronucleus, centrally positioned in cell, 5-7 μ m in length and 1-6 μ m in width (average $6.0 \times 4.6 \mu$ m, $n=21$). One micronucleus on macronucleus, 1-2 μ m in diameter (average 1.0 μ m in diameter, $n=4$) (Fig. 8C).

Occurrence and ecological characteristics. The Korean population was collected from Jinhae Bay and Gwangyang Bay in all seasons (water temperature of 4-26 $^{\circ}$ C and salinity of 2-34 psu). A maximum abundance (5,250 cells/L) was observed in Jinhae Bay in May, 2011 (water temperature of 18 $^{\circ}$ C and salinity of 23 psu) (Fig. 9).

Comparison with other population. According to the original description, the torch-like spiral anterior membranelles and the extremely long trichites among the cilia of anterior membranelles are unique characteristics in *Strombidium tressum* (Lynn et al., 1988). This population is smaller than original population (13-21 \times 10-15 μ m in this population vs. 21-29 \times 13-19 μ m in original population). Moreover, the original population has an apical protrusion, but protrusion on anterior end is hardly observed in the Korean population.

¹**Strombidium bilobum* Lynn and Gilron, 1993 (Table 1, Figs. 10, 11)

Strombidium bilobum Lynn and Gilron, 1993:50, figs. 1C, D, 2B.

Diagnosis. Body subconical with narrowed girdle area; size 31-36 μ m in length and 14-21 μ m in width after protargol impregnation; apical collar opened on ventral surface; anterior membranelles located on apical collar, composed of 14-17

Korean name: ¹*아령핵민소모충

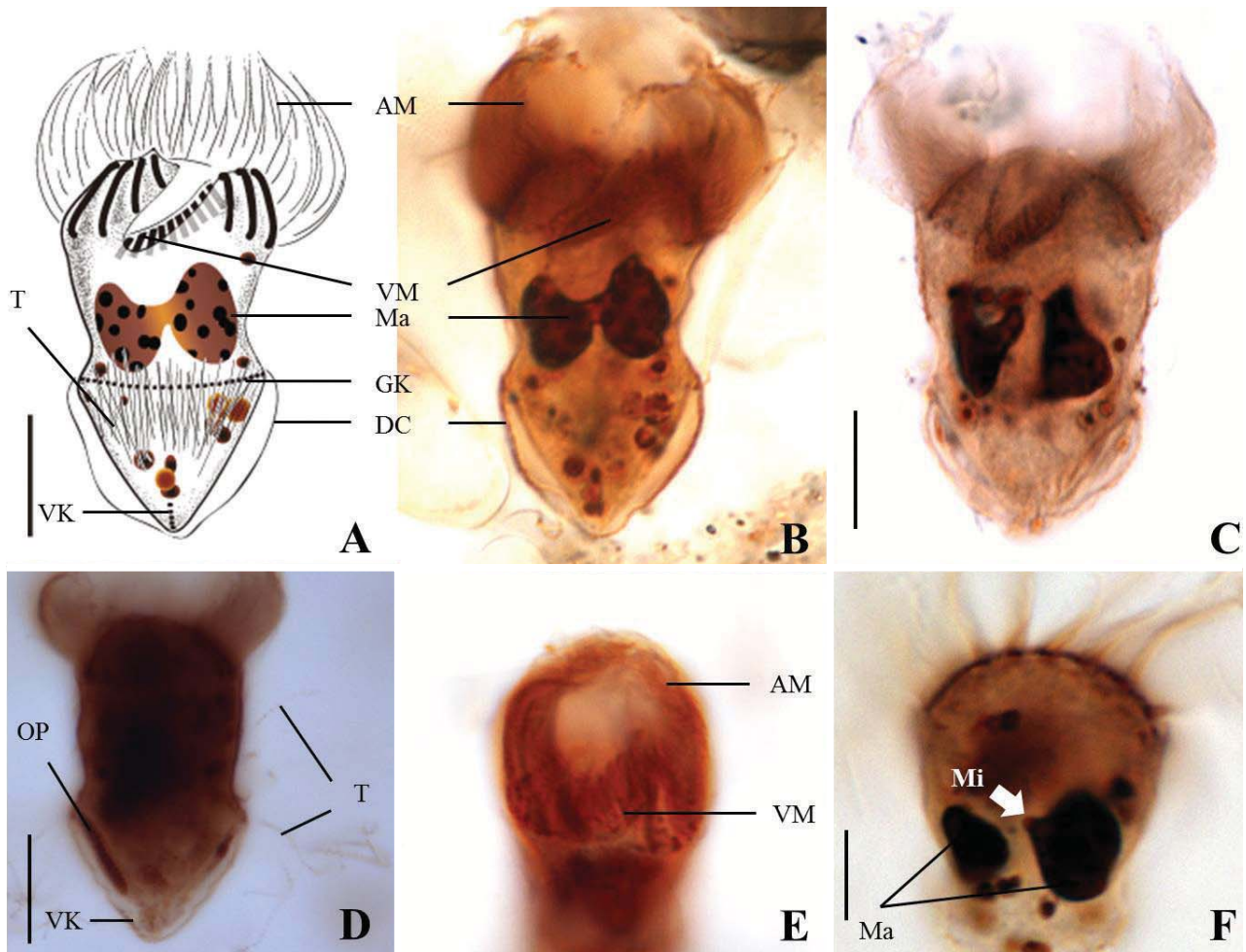


Fig. 10. *Strombidium bilobum* after protargol impregnation. A-C, Ventral view; D, Lateral view, oral primordium originated below girdle part and trichites extruded from body; E, Ventral membranelles almost covered by apical collar; F, Two macronuclear nodules. AM, anterior membranelles; DC, distended cell surface; GK, girdle kinety; Ma, macronucleus (or macronuclear nodules); Mi, micronucleus; OP, oral primordium; T, trichites; VK, ventral kinety; VM, ventral membranelles. Scale bars: A, C, D, F=10 μ m.

polykinetids; ventral membranelles covered by apical collar, composed of 9-13 polykinetids; horizontal girdle kinety composed of 36-40 dikinetics; vertical ventral kinety composed of 4-6 dikinetics; two ovoid macronuclear nodules or dumb-bell shaped macronucleus, about $8 \times 5 \mu\text{m}$ in size.

Morphological description of the Korean population.

Shape subconical, anterior cylindrical and posterior pointed, most cells slightly narrowed at girdle part (Fig. 10A-C). Size 31-36 μm in length and 14-21 μm in width (average $33.3 \times 17.8 \mu\text{m}$, $n=15$), cell length by width ratio about 2 : 1 after protargol impregnation. Trichites inserting on anterior of girdle kinety and internally extending posterior end of cell. Transparent distended cell surface expanded from girdle kinety to posterior of body (Fig. 10A, B).

Apical collar opened on ventral surface. Anterior membranelles surrounding apical collar and composed of 14-17

polykinetids (average 15 polykinetids, $n=11$). Ventral membranelles separated from anterior membranelles and obliquely lying on oral groove that extended into oral cavity and almost covered by the apical collar, composed of 9-13 polykinetids (average 11 polykinetids, $n=8$) (Fig. 10E). Distance from posterior end of ventral membranelles to posterior pole of cell about 21-27 μm (average 23.8 μm , $n=15$).

Somatic ciliature composed of girdle kinety and ventral kinety, no extra kinety detected. Girdle kinety, subequatorial positioned (3/5 of body length), completely surrounding the cell, composed of 36-40 dikinetics. Distance from girdle kinety to posterior pole of cell distance 12-15 μm (average 13.2 μm , $n=11$), Ventral kinety, vertically arranged from posterior pole of cell, composed of 4-6 dikinetics (average 5 dikinetics, $n=9$) (Fig. 10A, D).

Two ovoid (separating) macronuclear nodules or dumb-

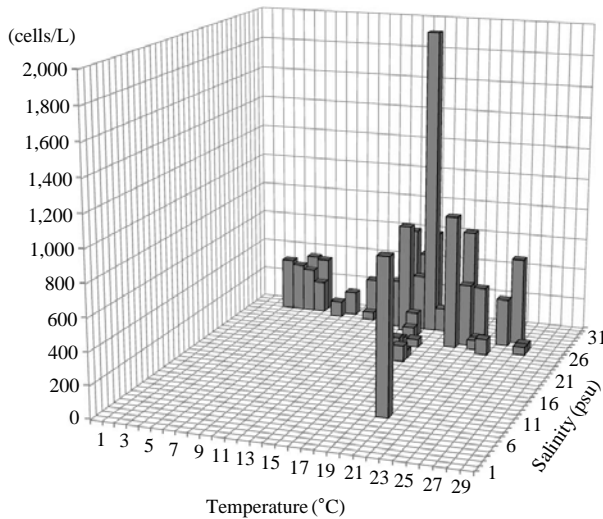


Fig. 11. Abundances of *Strombidium bilobum* occurred at different temperatures (°C) and salinities (psu).

bell shaped (connecting with each other) macronucleus, positioned near the posterior margin of ventral membranelles, one size 6-11 μm in length and 4-8 μm in width, another size 7-11 μm in length and 4-7 μm in width (average $8.8 \times 4.9 \mu\text{m}$, $8.0 \times 5.0 \mu\text{m}$, $n=15$) (Fig. 10B, C, F).

Oral primordium originated below girdle part and left portion of ventral side (Fig. 10D).

Occurrence and ecological characteristics. The Korean population was collected from Jinhae Bay and Gwangyang Bay in all seasons (water temperature of 4-27°C and salinity of 9-34 psu). The maximum abundance (1,950 cells/L) was observed in Jinhae Bay in May, 2011 (water temperature of 18°C and salinity of 31 psu) (Fig. 11).

Comparison with other population. *Strombidium bilobum* was first described from Kingston Harbour, Jamaica without any ecological data provided (Lynn and Gilron, 1993).

Compared with the Jamaican population, the Korean population has the similar shape, polykinetidal numbers, and bilobed macronucleus. However, there are two different morphological characteristics: the ventral membranelles are distinctly separated from anterior membranelles in the Korean population (vs. anterior membranelles continuous with the ventral membranelles in the Jamaica population) and sub-equatorial girdle kinety (vs. equatorial girdle kinety).

¹**Strombidium pollostomum* Lynn and Gilron, 1993

(Table 1, Figs. 12, 13)

Strombidium pollostomum Lynn and Gilron, 1993: 54, fig. 3C; Suzuki and Ota, 2011: 152, figs. 17, 18.

Diagnosis. Body hemisphere to semi-ovoid, posterior pointed; size 12-19 μm in length and 8-15 μm in width after protargol impregnation; oral groove opened on ventral surface of cell; anterior membranelles composed of 12-16 polykinetids; ventral membranelles continuous with anterior membranelles, composed of 4-6 polykinetids; subequatorial girdle kinety composed of 14-16 dikinetids; ventral kinety composed of 3-5 dikinetids; one spherical macronucleus, $6 \times 5 \mu\text{m}$ in size; one micronucleus, about 1 μm in diameter; small *Strombidium* species ($\leq 20 \mu\text{m}$).

Morphological description of the Korean population.

Hemisphere to semi-ovoid in body shape, posterior pointed (Fig. 12A-C, E). Cell size 12-19 μm in length and 8-15 μm in width (average $15.1 \times 10.7 \mu\text{m}$, $n=22$), cell length by width ratio=1.4 : 1 after protargol impregnation. No trichites found in body. A tiny globular drop on posterior of cell, 1-2 in number and 1 μm in diameter (average 1.1 μm in diameter, $n=10$) (Fig. 12A, B).

Oral groove opened on ventral surface of the cell. Anterior membranelles torch-like shaped and slightly sloped toward left side of cell, composed of 12-16 polykinetids (average 14 polykinetids, $n=19$). Ventral membranelles continuous with anterior membranelles, composed of 4-6 polykinetids (average 6 polykinetids, $n=19$), from posterior of ventral membranelles to posterior pole of cell distance 7-13 μm (average 10.0 μm , $n=18$) (Fig. 12B, C, E, G).

Somatic ciliature composed of girdle kinety and ventral kinety, no extra kinety detected. Girdle kinety, equatorial to subequatorial (1/2-1/3 from posterior end of cell), composed of 14-16 dikinetids (average 15 dikinetids, $n=2$), completely surrounding cell, from girdle kinety to posterior pole of cell distance 5-7 μm (average 6.1 μm , $n=2$). Ventral kinety vertically extending from posterior end, composed of 3-5 dikinetids (average 4 dikinetids, $n=8$) (Fig. 12D, E).

One spherical to ovoid macronucleus, containing many granules, $4-9 \times 3-7 \mu\text{m}$ (average $6.0 \times 4.9 \mu\text{m}$, $n=20$), positioned centrally. One micronucleus on macronucleus, 1 μm in diameter (average 1.1 μm in diameter, $n=5$) (Fig. 12C).

Occurrence and ecological characteristics. This species was collected from Jinhae Bay and Gwangyang Bay in all seasons (water temperature of 4-28°C and salinity of 9-34 psu). The maximum abundance (1,550 cells/L) of this species was observed in Jinhae Bay on May, 2011 (water temperature of 15°C and salinity of 31 psu) (Fig. 13).

Comparison with other population. *Strombidium pollostomum* was recorded from Jamaica in 1993, not including ecological data (Lynn and Gilron, 1993).

This species is very similar to the Jamaica population in shape, the continuous arrangement and polykinetid numbers

Korean name: ¹*극소민소모충

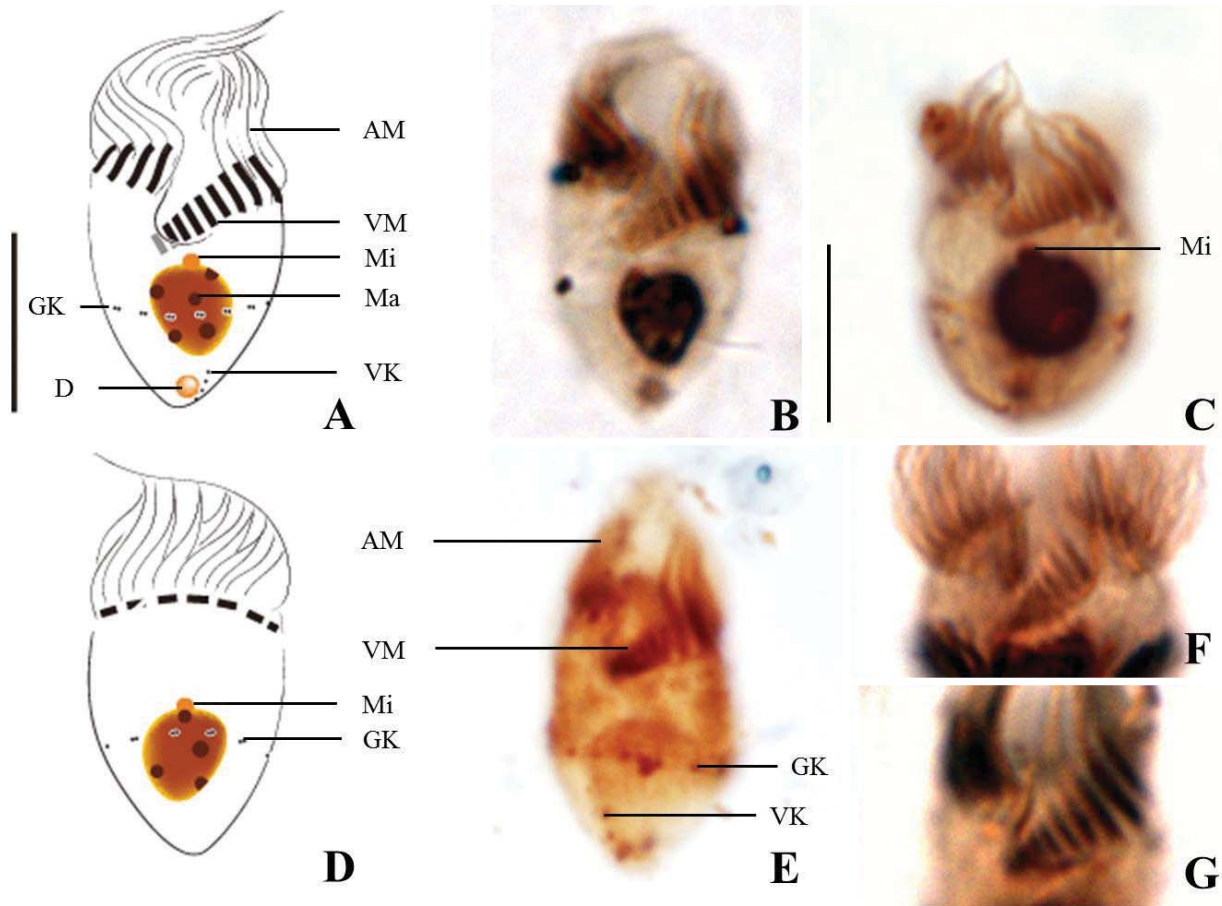


Fig. 12. *Strombidium pollostomum* after protargol impregnation. A-C, E, Ventral view; D, Dorsal view; F, Arrangement of oral membranelles from *S. epidemum* and G, from *S. pollostomum*. AM, anterior membranelles; GK, girdle kinety; Ma, macronucleus; Mi, micronucleus; D, a tiny globular drop at posterior end; VK, ventral kinety; VM, ventral membranelles. Scale bars: A, C=10 μ m.

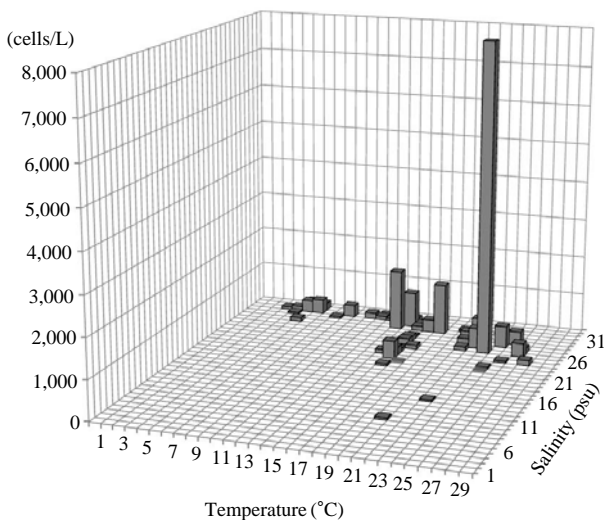


Fig. 13. Abundances of *Strombidium pollostomum* occurred at different temperatures ($^{\circ}$ C) and salinities (psu).

of anterior and ventral membranelles. However, the Korean population is bigger than the Jamaican population ($12-19 \times 8-15 \mu\text{m}$ vs. $9-14 \times 7-11 \mu\text{m}$) and has a globular drop on posterior of the cell.

Suzuki and Ota (2011) described a species under the name of *Strombidium* cf. *inclinatum* from Franklin Bay, Canada. Compared with *S. inclinatum* from original paper, *S. cf. inclinatum* has some differences that are not insignificant: fewer number of girdle kinety (14-15 dikinets in *S. cf. inclinatum* vs. over 40 dikinets in *S. inclinatum*) and ventral kinety (almost 2 dikinets vs. 7-9 dikinets), and the position of girdle kinety (posterior part in cell vs. almost equatorial) (Montagnes et al., 1990; Suzuki and Ota, 2011). We found the more similar species than *S. inclinatum* and suggested that *S. cf. inclinatum* might be *S. pollostomum*. *Strombidium* cf. *inclinatum* are very similar to *S. pollostomum*: ovoid cell shape, the number of anterior and ventral membranelles, ventral membranelles continuous with anterior

membranelles, the minor girdle kinety positioned posterior part, and unrecognizable trichites (Lynn and Gilron, 1993).

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