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Planktonic ciliates below sea ice in Franklin Bay, Canada

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Abstract: Planktonic ciliates below sea ice in Franklin Bay, Canada were studied in terms of their taxonomic composition and species descriptions. They occurred at an abundance of 2,400 cells L^{-1} and a biovolume of 4.24×10^6 μm^3 L^{-1}. Loricate ciliates (Tintinnida, Spirotrichea) occupied a very small percentage of the total both in terms of abundance (1.7%) and biovolume (1.9%). On the other hand, aloricate ciliates were predominant; in particular *Myrionecta rubra* (Cyclotrichida, Litostomatea) in terms of abundance (50%) and *Lohmaniella oviformis* (Choreotrichida, Spirotrichea) in terms of biomass (19.2%). Diagnoses and descriptions are given for ten aloricate species; eight of these species (*Leegaardiella ovalis*, *Lohmaniella oviformis*, *Tontonia gracillima*, *Strombidium acutum*, *S. constrictum*, *S. dalum*, *S. epidemum, Myrionecta rubra*) were identifiable in the present material. Compared with previous descriptions, six of these species (not *S. constrictum* or *M. rubra*) have more or less distinct characters incompatible with reported intraspecific variations.

Key words: Franklin Bay, planktonic ciliates, sea ice, species description

Introduction

Planktonic ciliates occur universally in the surface ocean and have been recognized as one of the important components in microbial food webs (e.g. Azam et al. 1983). Among the planktonic ciliates, aloricate forms are frequently predominant rather than tintinnid ciliates (e.g. Suzuki & Taniguchi 1998, Suzuki 1999). The former, however, have not been investigated globally especially from a faunistic viewpoint, because their taxonomic identification and morphological observations are generally laborious and time-consuming (Wilbert 1975, Montagnes & Lynn 1987). Furthermore, available criteria for their species identification are often insufficient for practical use, especially in small-sized species; descriptive information is limited and hence morphological variation in each species is not fully characterized compared with the situation in tintinnid ciliates. These difficulties prevent the development of further ecological studies on planktonic ciliates, such as population dynamics and studies of species diversity.

Sea ice is observed in higher latitudes, especially in winter, in both hemispheres and covers up to 7% of the earth's surface (Dieckmann & Hellmer 2003). It provides favorable habitats for ice algae and various consumers, especially around the boundary between the ice-bottom and the water column (Knox 1994, Schnack-Schiel 2003). Although planktonic ciliates may be an important component of the microbial fauna (Lizotte 2003), ecological information on them is extremely rare because the frigid climate is inhibitory for investigations. Fortunately, through a precious opportunity to collect planktonic ciliate specimens in ice-covered Franklin Bay, Canada, it has become possible to offer here some basic information on ciliate ecology below sea ice.

In this study, the taxonomic composition of planktonic ciliates dwelling below sea ice in Franklin Bay was investigated and detailed morphometrics of the dominant aloricate species were described to allow comparisons with previous descriptions. Furthermore, an attempt was made the biogeographic distribution of each aloricate species through referral to reliable articles published in the literature.

Materials and Methods

Sampling was carried out on 10 May 2004 at an overwintering station of CASES 2004 in Franklin Bay, Canada (70°02′N, 126°18′W; Fortier and Barber 2008). The water sample was collected with a Niskin-type water sampler at 0.2 m depth below the sea ice (1.8 m thickness). Water temperature and salinity were simultaneously measured with a CTD (Sea-Bird 9). Chlorophyll *a* concentration was mea-

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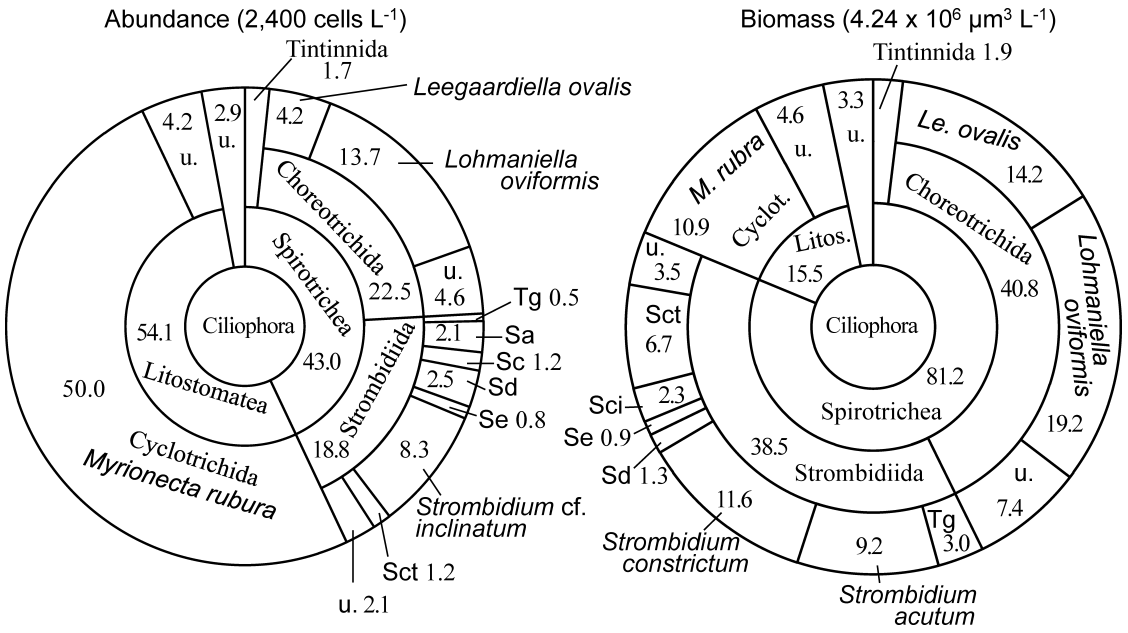

Fig. 1. Taxonomic compositions of planktonic ciliates that occurred below sea ice in Franklin Bay on 10 May 2004. Left circle is in terms of abundance and right one in biovolume. Numerals show percentage of each group. Sa: *Strombidium acutum*, Sc: *Strombidium constrictum*, Sd: *Strombidium dalum*, Se: *Strombidium epidemum*, Sci: S*trombidium* cf. *inclinatum*, Sct: *Strombidium* cf. *taylori*, Tg: *Tontonia gracillima*, u.: unidentified.

sured by fluorometry after filtration of a 100 mL water subsample onto a GF/F filter (Parsons et al. 1984). Specimens in 650 mL were fixed with Bouin's solution at a final concentration of 10%. After returning to the laboratory, ciliates were concentrated, impregnated and mounted with the quantitative protargol stain (QPS) method (Montagnes & Lynn 1987), while the two steps for producing a purple-gray tone, placing in the gold chloride solution and the following oxalic acid solution, were omitted following the general protargol impregnation method (e.g. Wilbert 1975) to observe microstructures more clearly. Enumeration and observation were done under a light microscope with oil immersion lenses of 20×, 40× and 100×. For species descriptions, as many well-conditioned specimens, e.g. cell body not being damaged by fixation and staining of an appropriate tone for detailed observations as possible, were selected. Eight permanent slides, where all plankters that occurred in the 650 mL sea water sample were stained with silver protein and mounted, without any missing, were deposited in the collection of the Faculty of Fisheries, Nagasaki University. Systematics is mainly according to Lynn & Small (2000).

Results and Discussion

Water temperature was −1.6°C and salinity was 30.7 psu. Chlorophyll *a* concentration was 0.53 µg L^{-1}. Among the autotrophic microplankton, diatoms were predominant (1.8×10^4 cells L^{-1}), especially pennate types (78%).

The standing crop of planktonic ciliates was 2,400 cells L^{-1} in terms of abundance and 4.24×10^6 µm^3 L^{-1} in biovolume without correcting for cell shrinkage due to Bouin's fixation (Fig. 1). Ciliate/chlorophyll *a* ratio was 4,530 cells µg^{-1}, which is in the higher half of the general range observed in the open ocean (100–10,000 cells µg^{-1}: Suzuki & Taniguchi 1998). Class Spirotrichea was predominant (81.2%) in terms of biovolume composition, while it was slightly subdominant (43.0%) to the class Litostomatea (54.1%) in terms of abundance. Among the spirotrich ciliates loricate forms (order Tintinnida) were a minor component (1.7% of abundance and 1.9% of biovolume); this subordinate tendency is the same as the general trend for the open ocean (Suzuki & Taniguchi 1998).

Cell size of planktonic ciliates ranged from 7 to 33 µm in equivalent spherical diameter (ESD) for Bouin's fixed specimens (Fig. 2): mean ESD was 13 µm and median was 10 µm. Even when the cell diameter is corrected with a QPS shrinkage factor of 0.74, which is estimated from a factor of 0.4 ($\sqrt[3]{0.4}\approx0.74$) measured in terms of cell volume (Jerome et al. 1993), more than 70% of individuals belonged to the nanoplankton category (2–20 µm).

Ten species were frequently observed and clearly identifiable: nine species belonged to the class Spirotrichea and the other to the class Litostomatea (Fig. 1). Descriptions of their morphology and other remarks, based on observations on their QPS specimens (Montagnes & Lynn 1987), are as follows.

Class Spirotrichea Bütschli, 1889
Subclass Choreotrichia Small & Lynn, 1985
Order Choreotrichida Small & Lynn, 1985

Suborder Leegaardiellina Laval-Peuto, Grain and Deroux, 1994

Family Leegaardiellidae Lynn & Montagnes, 1988

Genus *Leegaardiella* Lynn & Montagnes, 1988

***Leegaardiella ovalis* Lynn & Montagnes, 1988 (Figs 3 & 4, Table 1)**

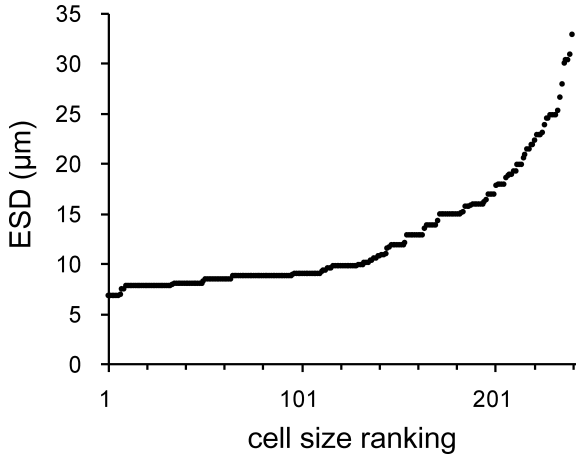

Fig. 2. Relationship between cell size ranking (from small to large) and cell size (equivalent spherical diameter: ESD) of planktonic ciliates under sea ice in Franklin Bay. Two hundred and thirty four individuals were randomly selected and investigated.

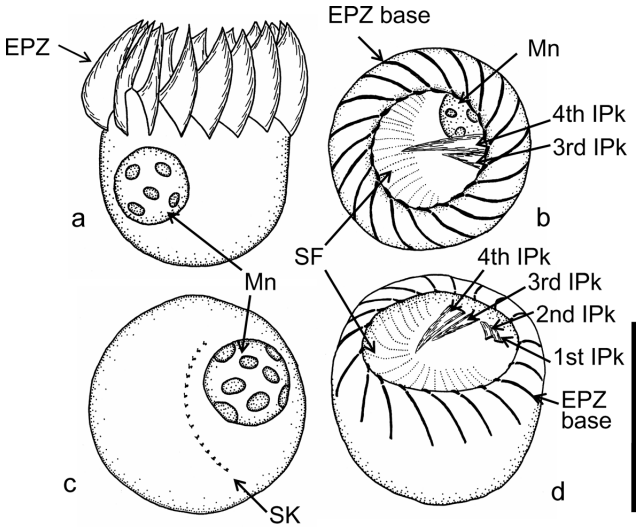

Fig. 3. Schematic figures of protargol-stained *Leegaardiella ovalis*. a, lateral view showing external polykinetid zone (EPZ) and a macronucleus (Mn); b, anterior view showing EPZ base composed of two segments, two internal polykinetids (IPk) (3rd and 4th in counter clockwise order), supportive fibers (SF) and Mn; c, posterior view showing an arched somatic kinety (SK) and Mn; d, anterior-lateral view showing IPk, SF and EPZ base composed of two segments. Scale bar: 20 µm.

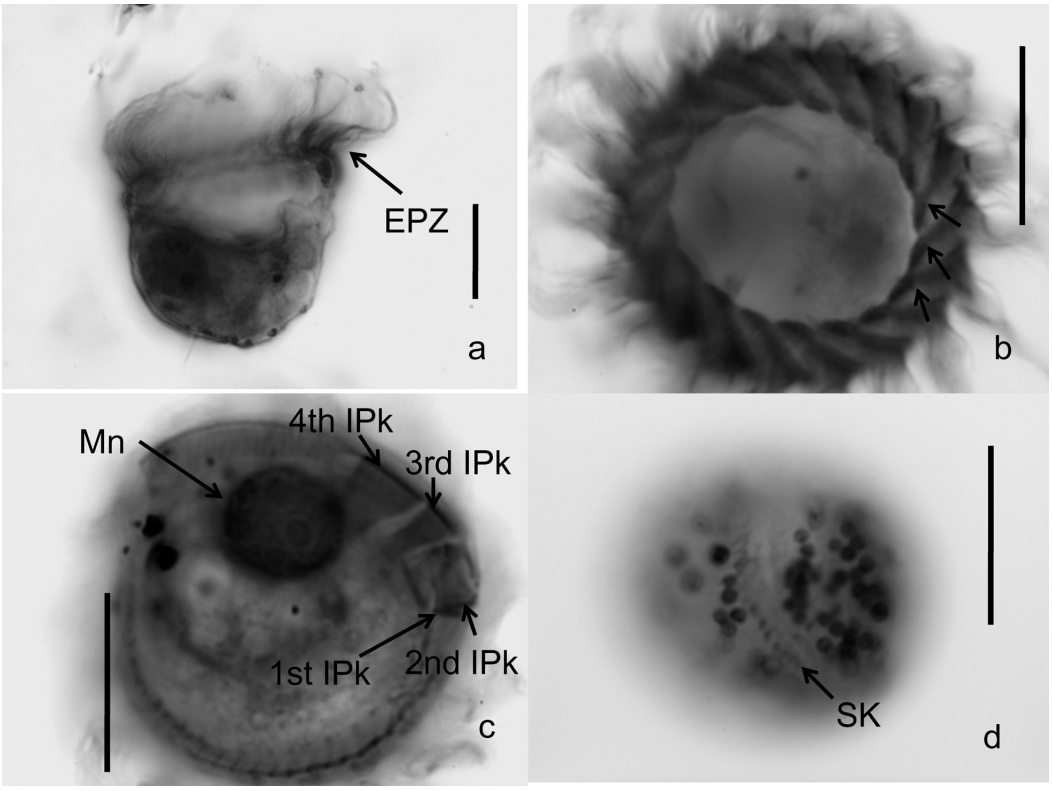

Fig. 4. Microphotographs of protargol-stained *Leegaardiella ovalis*. a, lateral view showing external polykinetid zone (EPZ); b, anterior view showing gaps between two segments in each external polykinetid (arrowed); c, anterior view showing a macronucleus (Mn) and four internal polykinetids (IPk) (direction of 1st and 2nd IPk is different from the others); d, posterior view showing an arched somatic kinety (SK) and many dark-stained particles. Scale bar: 10 µm.

Table 1. Morphological characteristics of two Choreotrichida species below sea ice in Franklin Bay.

Species	Cell shape	Length (μm)	Width (μm)	EPk[a] number	IPk[b] number	EPZ-IPZ[c] arrangement	SK[d] number	Mn[e] number	Mn shape
Leegaardiella ovalis	subspherical	15–28	22–28	19	4	separated	1	1	almost spherical
Lohmaniella oviformis	oval	13–22	11–17	19–20	5–8	partially separated	5	1	reniform

[a]EPK: External polykinetid; [b]IPK: Internal polykinetid; [c]EPZ-IPZ; External polykinetid zone-internal polykinetid zone; [d]SK: Somatic kinety; [e]Mn: Macronucleus.

Leegaardiella ovalis Lynn & Montagnes, 1988: 653, figs 8E-H.

Description. Cell subspherical, 15–28 μm (mean=20.3 μm, n=11) in length and 22–28 μm (mean=24.9 μm, n=15) in width. External polykinetid zone (EPZ) distinctly separated from internal polykinetid zone (IPZ). EPZ composed of 19 polykinetids (n=14), two unequal segments slightly separated. Internal polykinetids (IPk) lie above an acentric depression and are comprised of 4 polykinetids (n=6); two small, one middle and one large polykinetid in counterclockwise order in anterior view. Direction of the small polykinetids distinctly different from that of the other polykinetids; two small polykinetids face counterclockwise direction, while the others face towards the center. Supportive fibers (SF) observed in oral cavity. One somatic kinety (SK), composed of about 15 dikinetids with the single kinetosome ciliated, around the posterior pole in an arch-shaped arrangement. One macronucleus (Mn), almost spherical in shape, positioned near the IPZ: 8–12 μm (mean=9.8 μm, n=15) in length, 7–10 μm (mean=8.6 μm, n=14) in width. Dark-stained particulate substances, sometimes many, on the posterior surface.

Remarks and comparisons. The Franklin-Bay population is very similar to the Isles-of-Shoals population with respect to various morphometric characters such as length (15–28 μm vs. 18–29 μm), width (22–28 μm vs. 20–28 μm), external polykinetid number (19 vs. 18–19) and internal polykinetid number (4 vs. 3–5) (Lynn & Montagnes 1988). However, contrary to the previous description, it sometimes showed an almost insignificant separation of the EPZ between a small inner segment and a large outer one, while the extent of the separation was variable. Furthermore, the direction of the two small internal polykinetids is remarkable (counterclockwise vs. center).

Distribution. This species also occurs in mid- and high latitudes, e.g. Isles-of-Shoals (42°59′N, 70°37′W) (Lynn & Montagnes 1988) and Southern Ocean (71°S, 85°W and 67°S, 68°W) (Wickham & Berninger 2007). It might be distributed mainly in cold waters in both hemispheres.

Suborder Lohmanniellina Laval-Peuto, Grain & Deroux, 1994

Family Lohmaniellidae Montagnes & Lynn, 1991

Genus *Lohmaniella* Leegaard, 1915

***Lohmaniella oviformis* Leegaard, 1915 (Figs 5 & 6, Table 1)**

Lohmaniella oviformis Leegaard, 1915: 28–30, figs 19–20; Lynn & Montagnes, 1988: 649–650, figs 7A–D, 9A–B.

Description. Cell oval, 13–22 μm (mean=20.1 μm, n=8) in length and 11–17 μm (mean=15.6 μm, n=11) in width. External polykinetid zone (EPZ) composed of 19–20 polykinetids (mean=19.5 polykinetids, n=11). Internal polykinetid zone (IPZ) composed of 5–8 polykinetids (mean=6.0 polykinetids, n=7) and lies above acentric depression that leads to cytostome. IPZ partially separated from EPZ: three internal polykinetids (1st to 3rd in counterclockwise order in apical view) apparently separated, with the other internal polykinetids (IPk) continuous. IPk size decreases, especially in length (e.g. from 5 to 2 μm), in counterclockwise order. Five somatic kineties (SK) radiate from the posterior pole; each SK composed of 2–5 kinetids (the number sometimes differing among the five SKs in each individual). The kinetid mostly of the non-ciliated dikinetid type, while the non-ciliated monokinetid type is rarely observed. One reniform-shaped macronucleus, 8–11 μm (mean=9.5 μm, n=4) in longer axis by 6–8 μm (mean=6.6 μm, n=9) in shorter axis, positioned excentrically. Oral primordium observed near macronucleus during cell division.

Remarks and comparisons. The Franklin-Bay population is similar to the Isles-of-Shoals population in terms of length (13–22 μm vs. 11–21 μm), width (11–17 vs. 11–20), external polykinetid number (19–20 vs. 17–21) and IPk number (5–8 vs. 4–6) (Lynn & Montagnes 1988). It showed, however, differences in IPk arrangement (three IPk separated and the others continuous vs. all distinctly separated) and in SK kinetid type (mostly dikinetid vs. monokinetid). IPk arrangement and SK kinetid type might be somewhat variable among populations.

Distribution. This species also occurs in mid- and high latitudes, e.g. Isles-of-Shoals (42°59′N, 70°37′W) (Lynn & Montagnes 1988); central Barents Sea (72–76°N, 30–35°E) (Jensen & Hansen 2000); Limfjord (56°54′N, 9°09′E) (Andersen & Sørensen 1986), Ellis Fjold (68°37′S, 78°00′E) (Grey et al. 1997), while the latter three occurrences were recognized without protargol impregnation. It seems to be distributed mainly in cold waters in both hemispheres. Biomass of this species was 8.14×10^5 μm^3 L^{-1}, being the most dominant among the planktonic ciliates (19.2%); hence, this species might play an important ecological role below sea ice in Franklin Bay (Fig. 1).

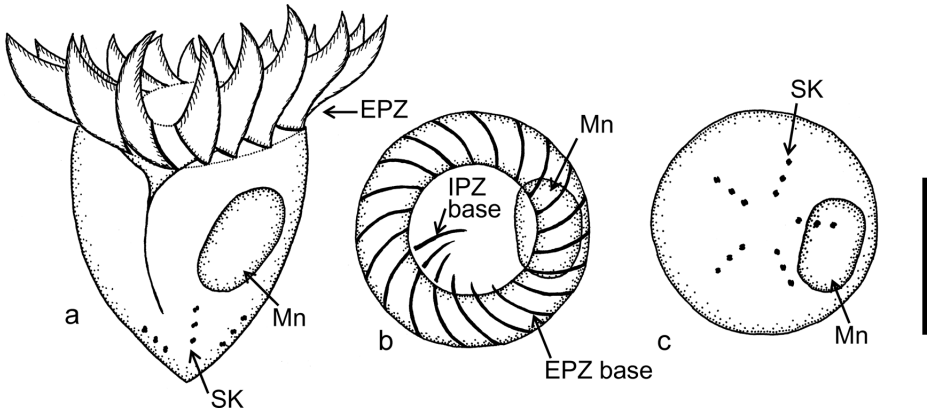

Fig. 5. Schematic figures of protargol-stained *Lohmaniella oviformis*. a, lateral view showing external polykinetid zone (EPZ), somatic kineties (SK) and a macronucleus (Mn); b, anterior view showing Mn, EPZ base and IPZ base; c, posterior view showing Mn and five SKs. Scale bar: 10 µm.

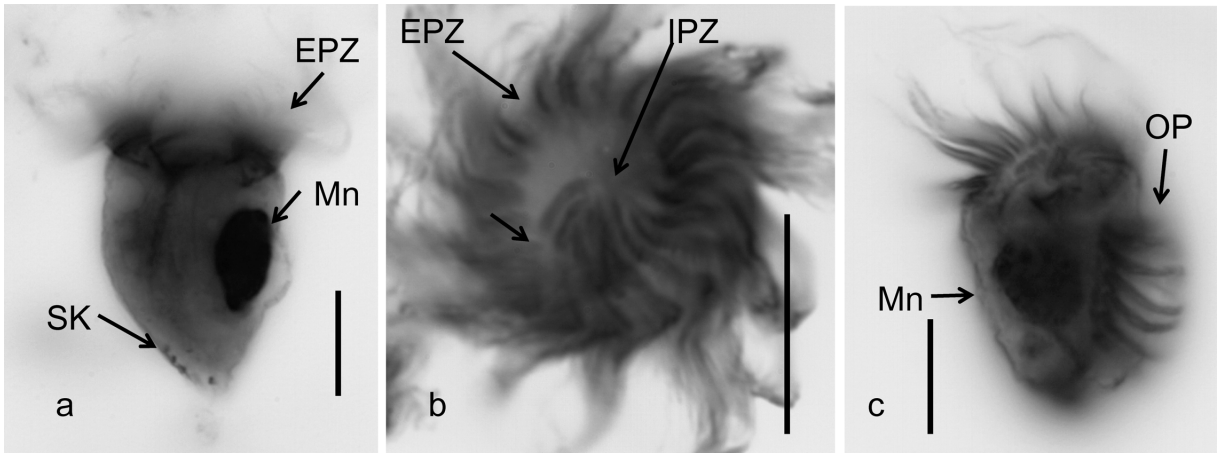

Fig. 6. Microphotographs of protargol-stained *Lohmaniella oviformis*. a, lateral view showing somatic kineties (SK), external polykinetid zone (EPZ) and a macronucleus (Mn); b, anterior view showing EPZ, internal polykinetid zone (IPZ) and three internal polykinetids (1st to 3rd in counterclockwise order) being separated from EPZ (arrowed); c, lateral view showing oral primordium (OP) near Mn. Scale bar: 10 µm.

Subclass Oligotrichia Bütschli, 1887
Order Strombidiida Petz & Foissner, 1992
Family Strombidiidae Fauré-Fremiet, 1970
Genus *Tontonia* Fauré-Fremiet, 1961
***Tontonia gracillima* Fauré-Fremiet, 1924 (Figs 7 & 8, Table 2)**

Tonotonia gracillima Fauré-Fremiet, 1924: 72–74, fig. 23; Kahl, 1932: 505–507, fig. 80 (34); Lynn et al., 1988: 261–264, figs 2A–C, 5AB.

Strombidium gracillimum Alekperov & Mamajeva, 1992: 11–12, fig. 3 (8).

Description. Cell semi-oval with oral groove, 26–35 µm (mean=30.0 µm, n=8) in length and 21–31 µm (mean=24.8 µm, n=8) in width. Tail (T) contracted, 20–27 µm (mean=22.1 µm, n=8) in length and 6–8 µm (mean=7.4 µm, n=8) in width; darkly stained fibre lying inside around the base. Anterior polykinetid zone (APZ) comprised of 13-15 polykinetids (mean=14.0 polykinetids, n=8), distinctly separated from ventral polykinetid zone (VPZ). Anterior polykinetids of equal length (15–20 µm), surrounding anterior end. VPZ comprised of 13–14 polykinetids (mean=13.5 polykinetids, n=8), lying in a wide ventral groove. Paroral (Po), 11–18 µm (mean=15.5 µm, n=8) in length, composed of ciliated kinetids, lying on the right lip of oral groove. Girdle (G) composed of many kinetids, maybe dikinetids with the one kinetosome ciliated, courses latitudinally at supraequatorial level on dorsal side and longitudinally on both lateral sides. Eight to eleven macronuclei (Mn), almost spherical and 3–6 µm in diameter. Trichites sometimes observed along the margin of oral groove. Many kinetosomes extending along tail.

Remarks and comparisons. The Franklin-Bay population is similar to the Isles-of-Shoals ciliates (Lynn et al. 1988) with respect to many morphometric characters, while the girdle kinetid type might be different (dikinetids with the one kinetosome ciliated vs. ciliated monokinetids). It is

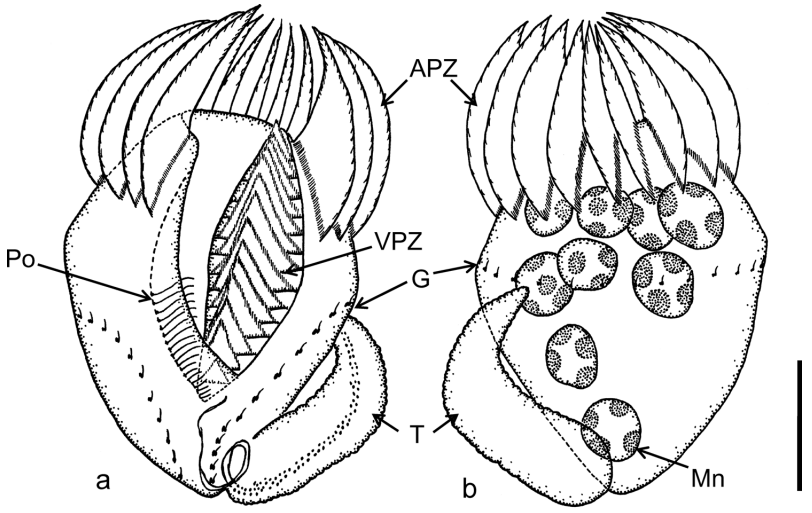

Fig. 7. Schematic figures of protargol-stained *Tontonia gracillima*. a, ventral view showing anterior polykinetid zone (APZ), ventral polykinetid zone (VPZ), paroral (Po), girdle (G) and tail (T); b, dorsal view showing macronuclei (Mn), APZ, G and T. Scale bar: 10 µm.

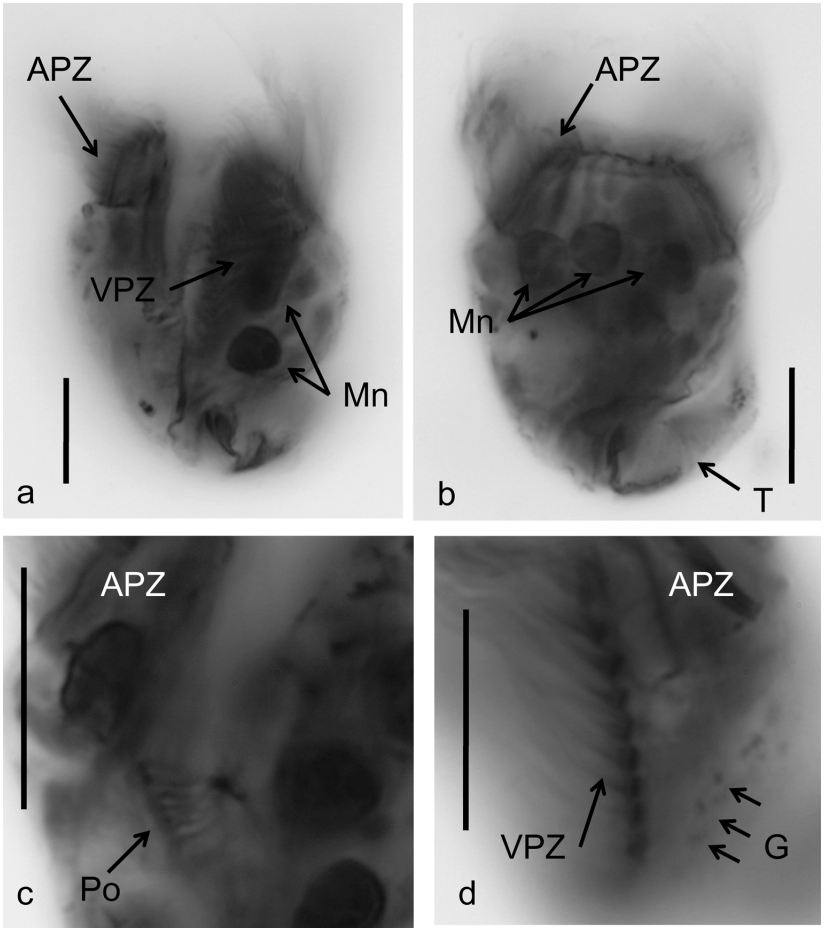

Fig. 8. Microphotographs of protargol-stained *Tontonia gracillima.* a, ventral view showing anterior polykinetid zone (APZ), ventral polykinetid zone (VPZ) and macronuclei (Mn); b, dorsal view showing APZ, Mn and tail (T); c, oral area showing APZ and paroral (Po) composed of ciliated kinetids; d, right-lateral view showing VPZ, APZ and girdle (G) composed of dikinetids with the single kinetesome ciliated. Scale bar: 10 µm.

rather different from the Chukchi-Bering population (Alekperov & Mamajeva 1992) with respect to body length (26–35 μm vs. 75–90 μm), ventral polykinetid number (13–14 vs. 10), anterior polykinetid number (13–15 vs. 25–30) and macronucleus number (8–10 vs. 35–50). Alekperov & Mamajeva (1992) suggested *T. gracillima* should be included in the genus *Strombidium*. We do not follow this recommendation, however, because the possession of a tail must be a sufficient criterion for generic separation.

Distribution. This species also occurs in mid- and high latitudes, e.g. Croisic Bay (47°N, 2°W) (Fauré-Fremiet 1924), the North Sea (56°N, 6°E) (Kahal 1932), Isles of Shoals (42°59′N, 70°37′E) (Lynn et al. 1988) and Chukchi and Bering Seas (63–68°N, 164–180°W) (Alekperov & Mamajeva 1992); while the former two occurrences were recognized without protargol impregnation. It might be distributed mainly in cold waters, at least in the northern hemisphere.

Genus *Strombidium* Claparède & Lachmann, 1858

***Strombidium acutum* Leegaard, 1915 (Figs 9 & 10, Table 2)**

Strombidium acutum Leegaard, 1915: 31, fig. 21; Lynn et al., 1988: 265, figs 2E, 5E–D; Montagnes et al., 1988: 195, figs 6a–b, 14–15.

Description. Cell wide conical posterior end and round conical anterior end, 23–38 μm (mean=29.5 μm, n=10) in

Table 2. Morphological characteristics of seven Strombidiida species below sea ice in Franklin Bay.

Species	Cell shape	Length (μm)	Width (μm)	APk[a] number	VPk[b] number	APZ-VPZ[c] arrangement	VK[d] kinetid number	Mn[e] number	Mn shape
Tontonia gracillima	semi-oval	26–35	21–31	13–15	13–14	separated	not observed	8–11	almost spherical
Strombidium acutum	wide conical posteriorly & round conical anteriorly	23–38	21–30	15	10–12	separated	7–12	1	almost spherical
Strombidium constrictum	conical with 'cap-like' posterior	39–45	28–33	15–16	11–13	separated	4	1	V-shaped
Strombidium dalum	conical	19–23	8–11	14–15	7–8	separated	4–6	1	conical
Strombidium epidemum	short conical	15–21	12–18	14–15	6–7	separated	3–4	1	almost spherical
Strombidium cf. *inclinatum*	conical posteriorly & cylindrical anteriorly	12–15	9–11	19–21 (APk+VPk)	—	continued	0 or 2	1	almost spherical
Strombidium cf. *taylori*	conical posteriorly & cylindrical anteriorly	26–42	20–31	15–16	10–14	separated	4–6	1	U-shaped

[a]APk: Anterior polykinetid; [b]VPk: Ventral polykinetid; [c]APZ-VPZ: Anterior polykinetid zone-ventral polykinetid zone; [d]VK: Ventral kinety; [e]Mn: Macronucleus.

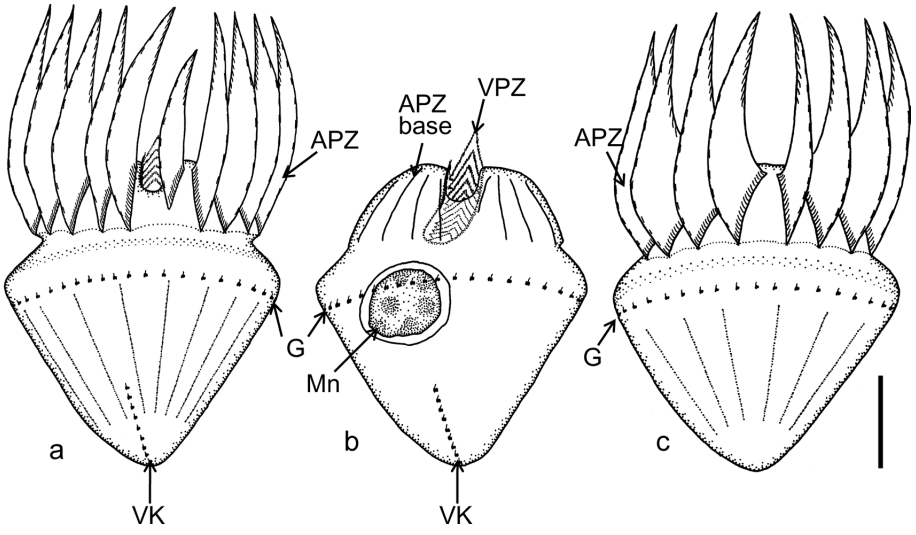

Fig. 9. Schematic figures of protargol-stained *Strombidium acutum*. a, ventral surface view showing anterior polykinetid zone (APZ), girdle (G) and ventral kinety (VK); b, ventral view showing APZ base, ventral polykinetid zone (VPZ), a macronucleus (Mn), G and VK; c, dorsal surface view showing APZ and G. Scale bar: 10 μm.

length and 21–30 µm (mean=25.7 µm, n=11) in width. An oral cavity enclosed by the ring of anterior polykinetid zone (APZ). APZ composed of 15 polykinetids (mean=15.0 polykinetids, n=11) surrounding anterior end, distinctly separated from ventral polykinetid zone (VPZ). Anterior polykinetids (APk) almost of equal length, while one APk, located beside the left margin of the oral groove, has a narrower base and is shifted anteriorly from the ring of APZ. VPZ comprised of 10–12 polykinetids (mean=10.5 polykinetids, n=11), lying in an oral groove entering posteriorly. Paroral lying on the upper right of the oral groove. Girdle (G) completely surrounding the cell equatorially, composed of dikinetids with the single kinetosome ciliated. Ventral kinety (VK) composed of 7–12 dikinetids with the single kinetosome ciliated. One macronucleus (Mn) almost spherical and covered with thin membrane, 8–13 µm (mean=10.1 µm, n=11) along longer axis by 8–11 µm (mean=9.4 µm, n=11) along shorter axis. Trichites numerous and variable in thickness (0.2–0.5 µm), inserting from the anterior area of G and extending internally towards posterior. Beaded strands sometimes recognizable around the APk.

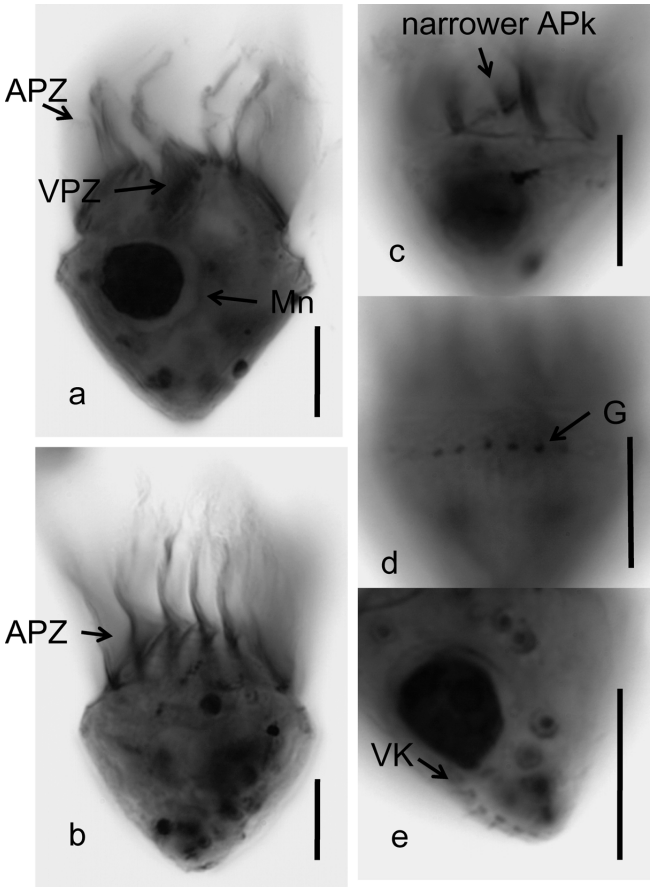

Fig. 10. Microphotographs of protargol-stained *Strombidium acutum*. a, ventral view showing anterior polykinetid zone (APZ), ventral polykinetid zone (VPZ) and a macronucleus (Mn); b, dorsal view showing APZ; c, right-lateral APZ area showing a narrower anterior polykintetid (APk) located beside the left margin of the oral groove; d, dorsal equatorial area showing girdle (G) composed of dikintids with the single kinetosome ciliated; e, posterior part showing ventral kinety (VK) composed of dikinetids with the single kinetosome ciliated. Scale bar: 10 µm.

Remarks and comparisons. The Franklin-Bay population is very similar to the Isles-of-Shoals population (Lynn et al. 1988) or the Perch-Pond population (Montagnes et al. 1988) in terms of the anterior polykinetid number (15 vs. 12–15 or 13–18) and ventral polykinetid number (10–12 vs. 10–22 or 9–15). However, they are slightly smaller (23–38 µm vs. 28–52 or 28–53 µm in length, 21–30 µm vs. 30–48 or 27–44 µm in width) and substantially differ with regards to the type of G kinetid (dikinetids vs. monokinetids), in VK number (7–12 dikinetids vs. not observed) and in APZ arrangement (one narrower APk shifted anteriorly vs. regularly arranged). A paroal kinety, which was observed in this population as well as in the Isles-of-Shoals population, was not recognized in the Perch-Pond population. These morphological characters may be more or less variable among populations.

Distribution. This species also occurs in mid- and high latitudes, e.g. the Isles of Shoals (42°59′N, 70°37′E) (Lynn et al. 1988), Perch Pond (41°34′N, 70°35′W) (Montagnes et al. 1988) and Ellis Fjold (68°37′S, 78°00′E) (Grey et al. 1997), with the lattermost recognized without protargol impregnation. It might be distributed mainly in cold waters in both hemispheres.

Strombidium constrictum (Meunier, 1910) Wulff, 1919 (Figs 11 & 12, Table 2)

Conocylis constricta Meunier, 1910: 147–148, pl. 10, figs 36–37.

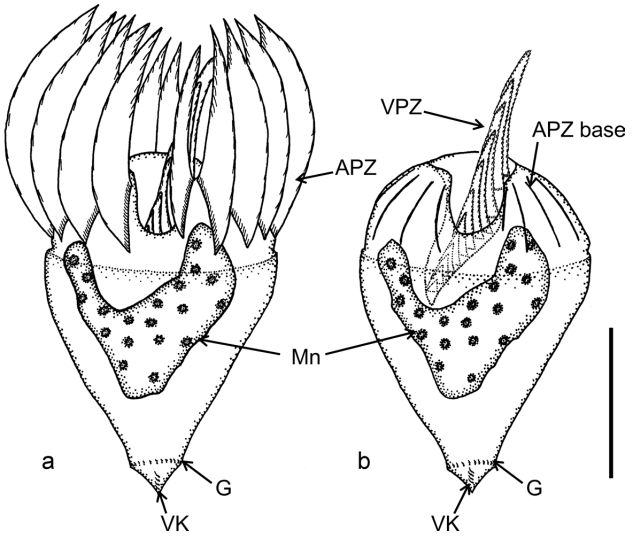

Fig. 11. Schematic figures of protargol-stained *Strombidium constrictum*. a, ventral view showing anterior polykinetid zone (APZ), a macronucleus (Mn), girdle (G) and ventral kinety (VK); b, ventral view showing APZ base, ventral polykinetid zone (VPZ), Mn, G and VK. Scale bar: 20 µm.

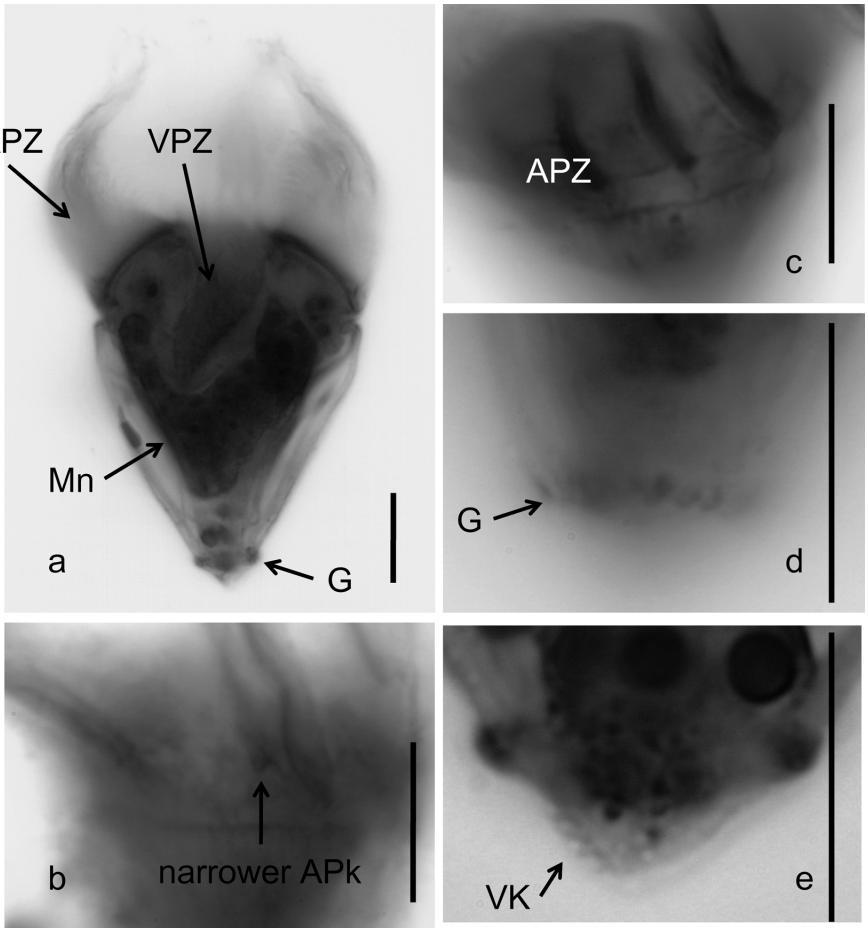

Fig. 12. Microphotographs of protargol-stained *Strombidium constrictum.* a, ventral view showing anterior polykinetid zone (APZ), ventral polykinetid zone (VPZ), a macronucleus (Mn) and girdle (G); b, APZ area showing a narrower anterior polykinetid (APk) located beside the left margin of the oral groove; c, dorsal view showing APZ; d, posterior part showing girdle (G) composed of dikintids with the single kinetosome ciliated; e, posterior part showing ventral kinety (VK) composed of dikinetids with the single kinetosome ciliated. Scale bar: 10 µm.

Strombidium constrictum Wulff, 1919: 115, fig. 24; Lynn et al., 1988: 269, figs 3C–E, 6C–D; Lynn & Gilron, 1993: 63–64.

Description. Cell conical with 'cap-like' posterior end, 39–45 µm (mean=41.8 µm, n=5) in length and 28–33 µm (mean=30.0 µm, n=5) in width. A deep buccal cavity almost enclosed by the ring of the anterior polykinetid zone (APZ). APZ composed of 15–16 polykinetids (mean=15.4 polykinetids, n=5) distinctly separated from ventral polykinetid zone (VPZ). Anterior polykinetids (APk) almost of equal length surrounding anterior end, while one APk located beside the right margin of the oral groove has a narrower base and is shifted anteriorly from the ring of APZ. VPZ composed of 11–13 polykinetids (mean=12.0 polykinetids, n=2) lying in the deep buccal cavity. Paroral not observed. Girdle (G) composed of 23–30 dikinetids (mean=25.4 dikinetids, n=5) with the single kinetosome ciliated, profoundly subequatorial, completely surrounding the cell. Ventral kinety (VK) composed of 4 dikinetids with the single kinetosome ciliated. One "V"-shaped macronucleus (Mn) positioned around buccal cavity. Trichites inserting from the posterior area of the APZ and extending internally towards G.

Remarks and comparisons. The Franklin-Bay population is very similar to the Kingston-Harbour population (Lynn & Gilron 1993) and the Isles-of-Shoals population (Lynn et al. 1988) in cell size (39–45 µm vs. 22–34 µm or 39–51 µm in length, 22–33 µm vs. 17–20 µm or 28–39 µm in width), anterior polykinetid number (15–16 vs. 14 or 14), ventral polykinetd number (11–13 vs. 9–11 or 8–14). Although there have been only three descriptions based on protargol-impregnated specimens, morphometric variation might be small among the populations.

Distribution. This species occurs in various areas, e.g. Kingston Harbour (17°58′N, 76°48′W) (Lynn & Gilron 1993), Isles-of-Shoals (42°59′N, 70°37′W) (Lynn et al. 1988) and Grand-Entrée Lagoon (47°N, 61°W) (Trottet et al. 2007), with the lattermost recognized without protargol impregnation. It might be a eurythermal species that is widely distributed, at least in the northern hemisphere.

***Strombidium dalum* Lynn, Montagnes & Small, 1988 (Figs 13 & 14, Table 2)**

Strombidium dalum Lynn, Montagnes & Small, 1988: 265–267, fig. 3A, 5F; Lynn & Gilron, 1993: 62, figs 2C, 7C; Pettigrosso, 2003: 124, fig. 11.

Description. Cell conical, 19–23 μm (mean=22.1 μm, n=7) in length and 8–11 μm (mean=9.6 μm, n=7) in width. Oral groove almost enclosed by the ring of the anterior polykinetid zone (APZ). APZ distinctly separated from ventral polykinetid zone (VPZ) and composed of 14–15 polykinetids (mean=14.6, n=7) of equal length surrounding anterior part. VPZ composed of 7–8 polykinetids (mean=7.4 polykinetids, n=5) and lying in a narrow ventral groove. Paroral not observed. Girdle (G) completely surrounding the cell equatorially, composed of 15–21 dikinetids (mean=17.0 dikinetids, n=7) with the single kinetosome ciliated. Ventral kinety (VK) composed of 4–6 dikinetids (mean=5.1, n=7) with the anterior kinetosome ciliated. One conical macronucleus (Mn), 6–10 μm (mean=7.6 μm, n=7) in length and 4–7 μm (mean=5.6 μm, n=7) in maximum width. Trichites not clearly observed. A weakly-stained tail like structure (TLS), about 5 μm in length and 2 μm in width, sometimes observed at posterior end.

Remarks and comparisons. The Franklin-Bay population is very similar to the Isles-of-Shoals population (Lynn et al. 1988), the Kingston-Harbour population (Lynn & Gilron 1993), and the Puerto-Cuateros population (Pettigrosso 2003). It has, however, some different morphological characters such as body length (19–23 μm vs. 13–18 μm in Isles-of-Shoals population), girdle kinetid type (dikinetids vs. monokinetids in Isles-of-Shoals population), kinetid number of ventral kinety (4–6 vs. 0 in Isles-of-

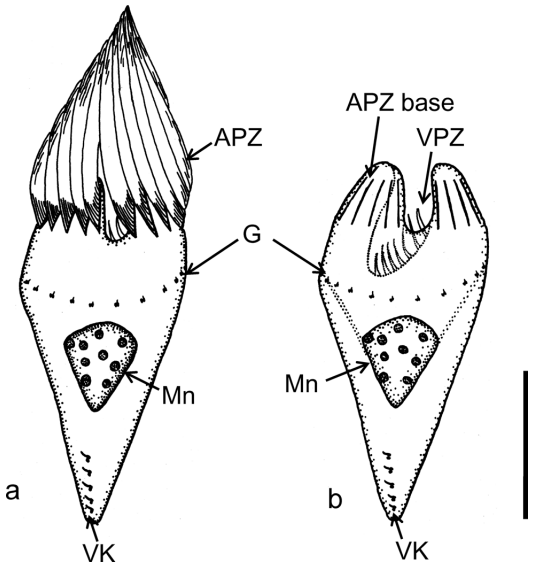

Fig. 13. Schematic figures of protargol-stained *Strombidium dalum*. a, ventral view showing anterior polykinetid zone (APZ), girdle (G), a macronucleus (Mn) and ventral kinety (VK); b, ventral view showing APZ base, ventral polykinetid zone (VPZ), G, Mn and VK. Scale bar: 10 μm.

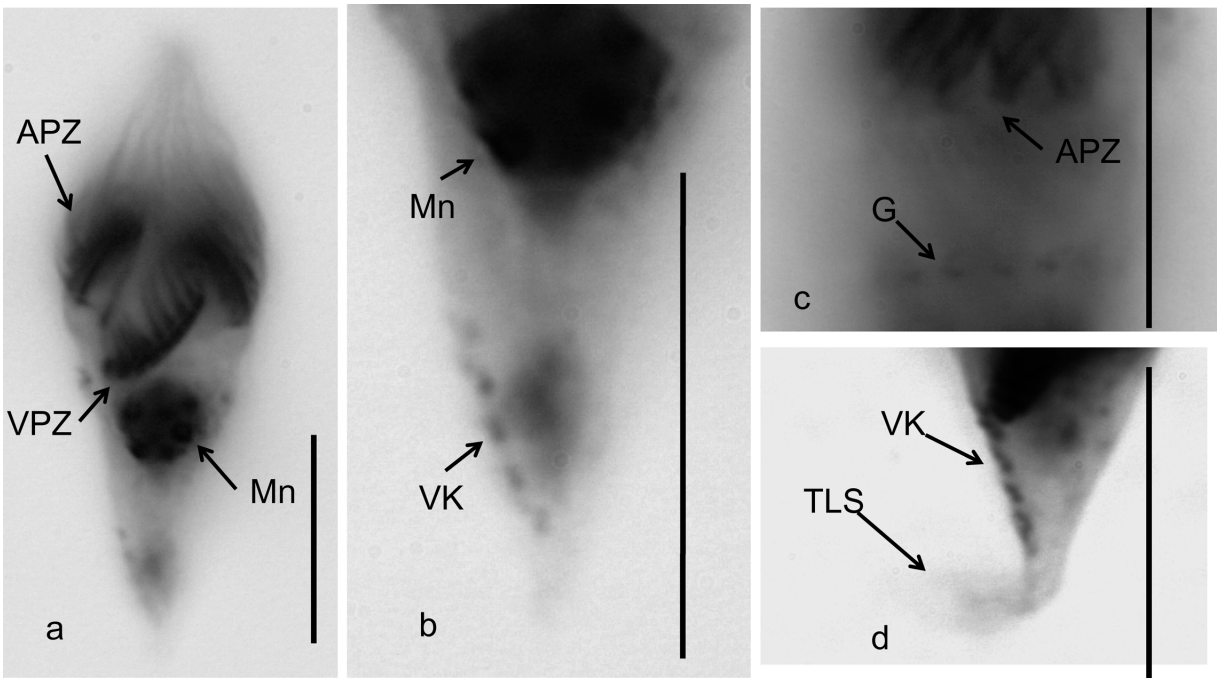

Fig. 14. Microphotographs of protargol-stained *Strombidium dalum*. a, ventral view showing anterior polykinetid zone (APZ), ventral polykinetid zone (VPZ) and a macronucleus (Mn); b, posterior part showing Mn and ventral kinety (VK) composed of dikinetids with the anterior kinetosome ciliated; c, dorsal part showing APZ and girdle (G) composed of dikinetids with the single kinetosome ciliated; d, posterior view showing VK and tail-like structure (TLS). Scale bar: 10 μm.

Shoals and Puerto-Cuatreos populations, or 3 in Jamaica population) and anterior polykinetid style (spiraled torch-like vs. straight in Kingston-Harbour and Puerto-Cuatreros populations). These morphological characters might be more or less variable among populations.

Distribution. This species also occurs in various areas, e.g. Isle of Shoals (42º59′N, 70°37′W) (Lynn et al. 1988), Puerto Cuatreros (39°S, 62°W) (Pettigrosso 2003), San Marcos Beach (43°26′N, 00°14′W) (Fernandez-Leborans & Fernandez-Fernandez 1999) and Kingston Harbour (17°58′N, 76°48′W) (Lynn & Gilron 1993). It might be a eurythermal species and be widely distributed in both hemispheres.

Strombidium epidemum Lynn, Montagnes & Small, 1988 (Figs 15 & 16, Table 2)

Strombidium epidemum Lynn, Montagnes & Small, 1988: 267–269, figs 3B, 6A–B; Lynn & Gilron, 1993: 62, figs 5A, 7A–B.

Description. Cell short conical, 15–21 µm (mean=17.2 µm, n=10) in length and 12–18 µm (mean=14.5 µm, n=11) in width. An oral cavity fairly exposed on the ventral surface. Anterior polykinetid zone (APZ) composed of 14–15 polykinetids (mean=14.2 polykinetids, n=11),

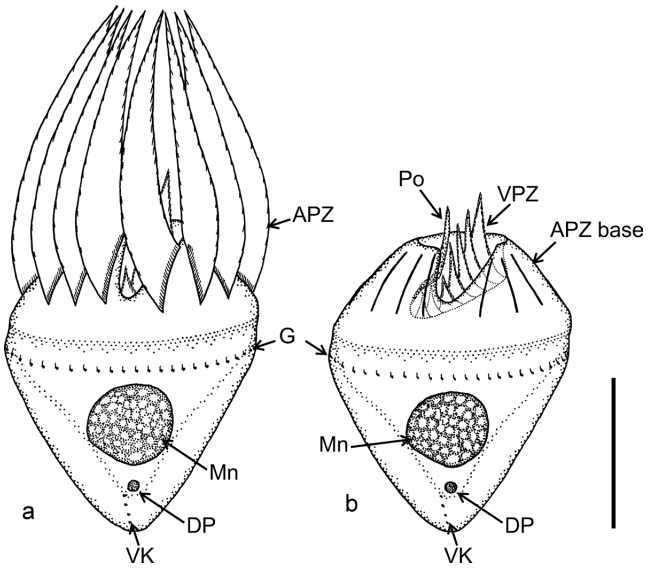

Fig. 15. Schematic figures of protargol-stained *Strombidium epidemum*. a, ventral view showing anterior polykinetid zone (APZ), girdle (G), a macronucleus (Mn), a dark-stained particle (DP) and ventral kinety (VK); b, ventral view showing paroral (Po), ventral polykinetid zone (VPZ), APZ base, G, Mn, DP and VK. Scale bar: 10 µm.

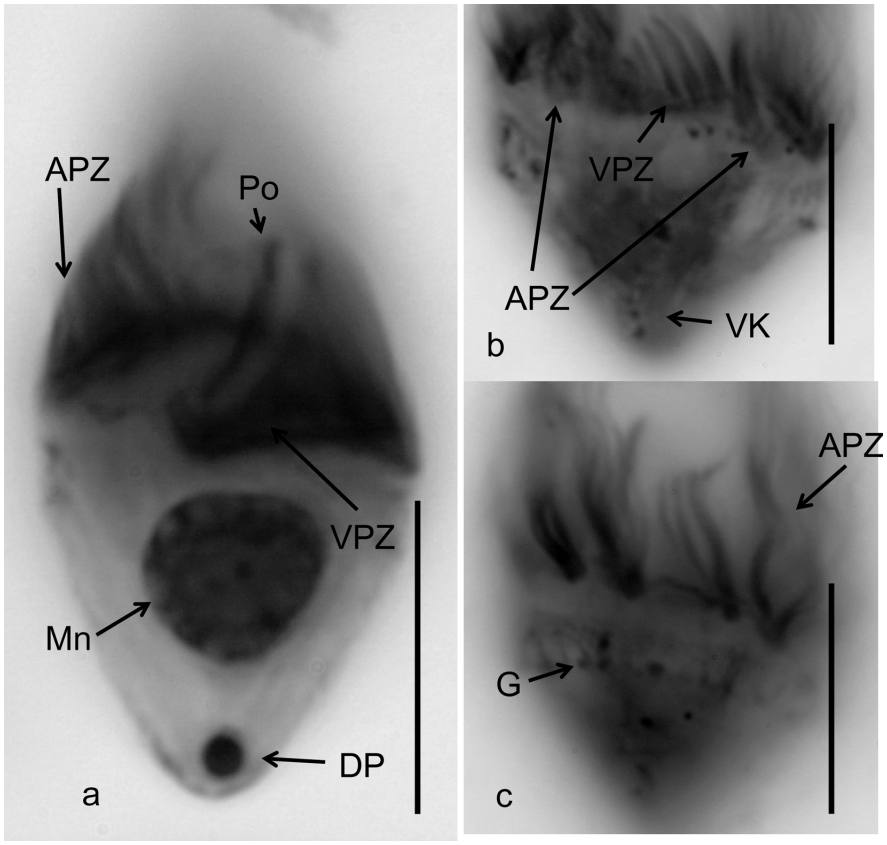

Fig. 16. Microphotographs of protargol-stained *Strombidium epidemum.* a, ventral view showing anterior polykinetid zone (APZ), ventral polykinetid zone (VPZ), a macronucleus (Mn), paroral (Po) and a dark-stained particle (DP); b, ventral surface showing ventral kinety (VK), APZ and VPZ; c, ventral surface showing APZ and girdle (G) composed of dikinetids with the single kinetosome ciliated. Scale bar: 10 µm.

clearly separated from ventral polykinetid zone (VPZ). Anterior polykinetids (APk) of equal length and surrounding anterior end. VPZ composed of 6–7 polykinetids (mean=6.4 polykinetids, n=11), lying obliquely in a ventral groove. Paroral (Po) frequently recognizable, a long polykinetid extending anteriorly at the right margin of the oral groove. Girdle (G) dikinetids with the single kinetosome ciliated, completely surrounding the cell equatorially. Ventral kinety (VK) recognizable, usually 3 or 4 kinetids; while kinetid type was not determinable. One macronucleus (Mn) almost spherical, 5–9×4–8 μm (mean=6.7×6.1 μm, n=11), positioned slightly posteriorly within the cell. Trichites inserting around G and extending internally towards posterior end. One dark-stained particle (DP), 0.5–2 μm (mean=1.4 μm, n=9) in diameter, mostly positioned around posterior end.

Remarks and comparisons. The Franklin-Bay population is very similar to the Kingston-Harbour population (Lynn & Gilron 1993) in many morphological characters such as cell length (15–21 μm vs. 14–23 μm), APk number (14 vs. 12–15), ventral polykinetid number (6–7 vs. 5–7), girdle kinetid type (dikinetids with the single kinetosome ciliated) and VK (3–4 kinetids vs. 2–4 kinetids). On the other hand, it was slightly different from the Isles-of-Shoals population (Lynn et al. 1988) with respect to cell length (15–21 μm vs. 9–14 μm), girdle kinetid type (dikinetids vs. monokinetids) and VK (3–4 kinetids vs. not observed). Furthermore, the dark-stained particle and a paroral kinety are newly recognized in this population.

Distribution. These morphological characters might be variable among populations. This species also occurs in various areas, e.g. Arou Beach (43°12′N, 9°07′E) (Fernandez-Leborans & Novillo 1992), Cantabrian Sea (43°22′N, 00°28′W) (Fernandez-Leborans 2001), Plymouth Sound (50°20′N, 4°09′W) (Leakey et al. 1994), Isles of Shoals (42°59′N, 70°37′W) (Lynn et al. 1988) and Kingston Harbour (17°58′N, 70°48′W) (Lynn & Gilron 1993). It might be a eurythermal species and be widely distributed, at least in the northern hemisphere.

Strombidium cf. *inclinatum* Montagnes, Taylor & Lynn, 1990 (Figs 17 & 18, Table 2)

cf. *Strombidium inclinatum* Montagnes, Taylor & Lynn, 1990: 321–322, figs 3–8; Modeo et al., 2003: 178–180, figs 3h–n, 6–7.

Description. Cell conical posteriorly and cylindrical anteriorly, 12–15 μm (mean=13.4 μm, n=10) in length and 9–11 μm (mean=9.7 μm, n=10) in width. Anterior polykinetid zone (APZ) slanted and continues to ventral polykinetid zone (VPZ). APZ and VPZ composed of 19–21 polykinetids together. Anterior polykinetid length 6–9 μm and ventral polykinetid length 2.5–6 μm. Paroral (Po) frequently recognized. Single macronucleus (Mn) almost spherical, 3.5–6 μm in diameter (mean=4.9 μm, n=10). Micronucleus not recognized. Girdle (G) subequatorial, composed of 14–15 dikinetids, at about 1 μm intervals, with the single kinetosome ciliated. Ventral kinety (VK) sometimes recognizable, composed of 2 dikinetids with the single kinetosome ciliated. Trichite not recognizable. One dark-stained particle (DP), about 0.8 μm in diameter, sometimes positioned near posterior end.

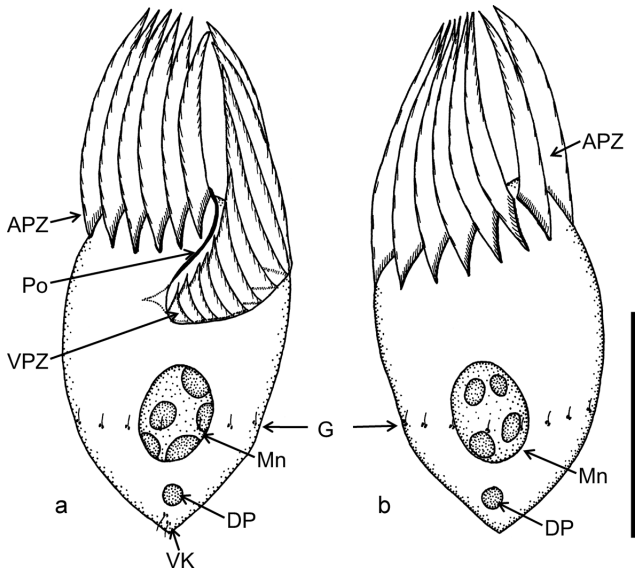

Fig. 17. Schematic figures of protargol-stained *Strombidium* cf. *inclinatum*. a, ventral view showing anterior polykinetid zone (APZ), paroral (Po), ventral polykinetid zone (VPZ), a macronucleus (Mn), girdle (G), a dark-stained particle (DP) and ventral kinety (VK); b, dorsal view showing APZ, Mn, G and DP. Scale bar: 10 μm.

Remarks and comparisons. This species is similar to *Strombidium inclinatum* sensu Montagnes et al., 1990 (Montagnes et al. 1990) or sensu Modeo et al., 2003 (Modeo et al. 2003) with respect to many morphological characteristics. However, there are some differences: it is smaller in body size (12–15×9–11 μm vs. 12.5–30×12.5–21 μm or 14–32×15–28 μm) and macronucleus size (3.5–6 μm vs. 4–12 μm or 6–12.5 μm), shorter in anterior polykinetid length (6–9 μm vs. 15 μm or 12–17 μm), fewer number of girdle kinetids (14–15 vs. 44–48 from figures or 32–44), fewer in number of VK kinetids (at most 2 vs. 7–9 or 5–9) and the girdle position is more posterior (subequatorial vs. almost equatorial or equatorial). The latter three inconsistencies are likely to not be trivial. Since cell size is too small to observe morphological characters in detail, this population could not be identified undoubtedly as *Strombidium inclinatum* in the present study.

Strombidium cf. *taylori* Martin & Montagnes, 1993 (Figs 19 & 20, Table 2)

cf. *Strombidium taylori* Martin & Montagnes, 1993: 538–539, figs 4–5.

Description. Cell conical posteriorly and cylindrical anteriorly, 26–42 μm (mean=31.1 μm, n=12) in length and 20–31 μm (mean=23.9 μm, n=12) in width. A deep oral

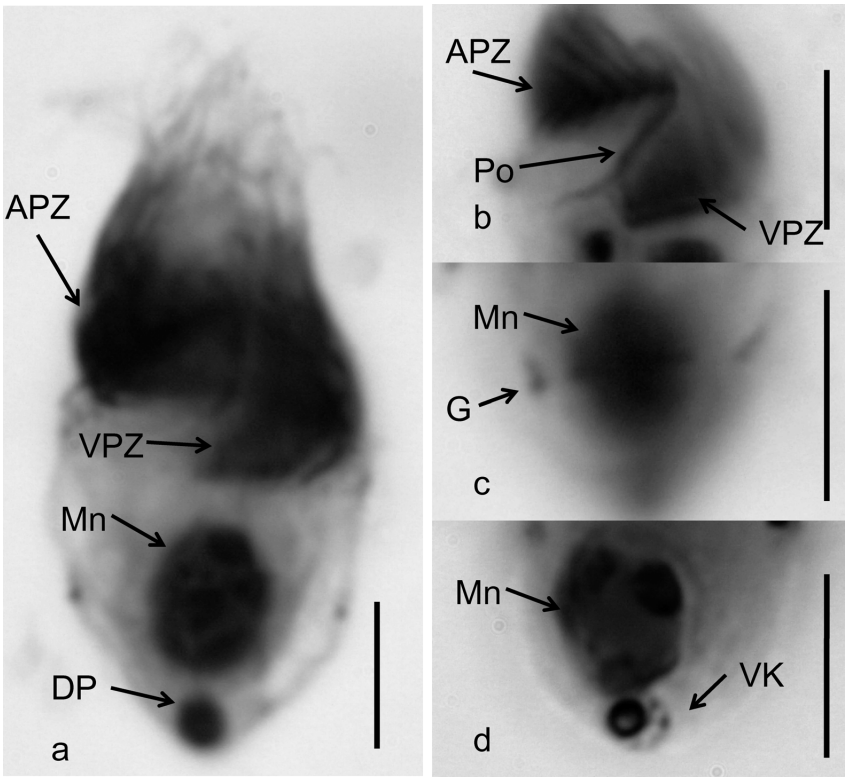

Fig. 18. Microphotographs of protargol-stained *Strombidium* cf. *inclinatum*. a, ventral view showing anterior polykinetid zone (APZ), ventral polykinetid zone (VPZ), a macronucleus (Mn) and a dark-stained particle (DP); b, oral area showing paroral (Po), APZ and VPZ; c, equatorial area showing Mn and Girdle (G) composed of dikinetids with the single kinetosome ciliated; d, posterior part showing Mn and ventral kinety (VK) composed of dikinetids with the single kinetosome ciliated. Scale bar: 5 µm.

cavity mostly enclosed by the ring of the anterior polykinetid zone (APZ). APZ composed of 15–16 polykinetids (mean=15.3 polykinetids, n=12), distinctly separated from ventral polykinetid zone (VPZ). Anterior polykinetids (APk), frequently tapering towards the apical end, almost of equal length and surrounding anterior end, while one APk is located beside the left margin of the oral groove and has a narrower base and is slightly shifted anteriorly from the ring of the APZ. VPZ composed of 10–14 polykinetids (mean=12.3 polykinetids, n=8), lying in deep oral groove. Ventral polykinetids becoming smaller posteriorly. Paroral kinety not recognizable. Girdle (G), composed of 20–30 dikinetids with the single kinetosome ciliated, surrounding the cell equatorially. Ventral kinety (VK) comprised of 4–6 dikinetids (mean=4.9 dikinetids, n=6) with the single kinetosome ciliated. One "U"-shaped macronucleus (Mn) positioned around buccal cavity. Thick trichites (Tr) inserting from the anterior neighborhood of girdle and extending internally towards posterior. Many dark-stained particles observable inside.

Remarks and comparisons. This species is similar to *Strombidium taylori* sensu Martin & Montagnes, 1993 (Martin & Montagnes 1993) with respect to various morphometrics, such as length (26–42 µm vs. 21–37 µm), width (20–31 µm vs. 17–39 µm), APk number (15–16 vs. 13–16),

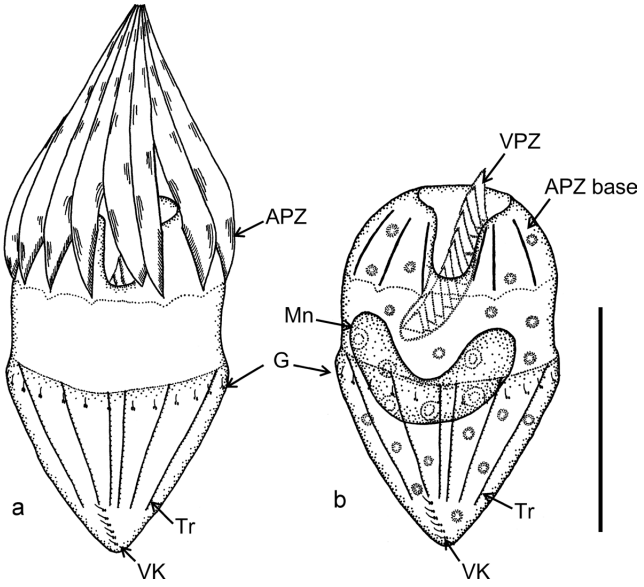

Fig. 19. Schematic figures of protargol-stained *Strombidium* cf. *taylori*. a, ventral surface showing anterior polykinetid zone (APZ), girdle (G), trichites (Tr) and ventral kinety (VK); b, ventral view showing ventral polykinetid zone (VPZ), APZ base, a macronucleus (Mn), G, Tr and VK. Scale bar: 20 µm.

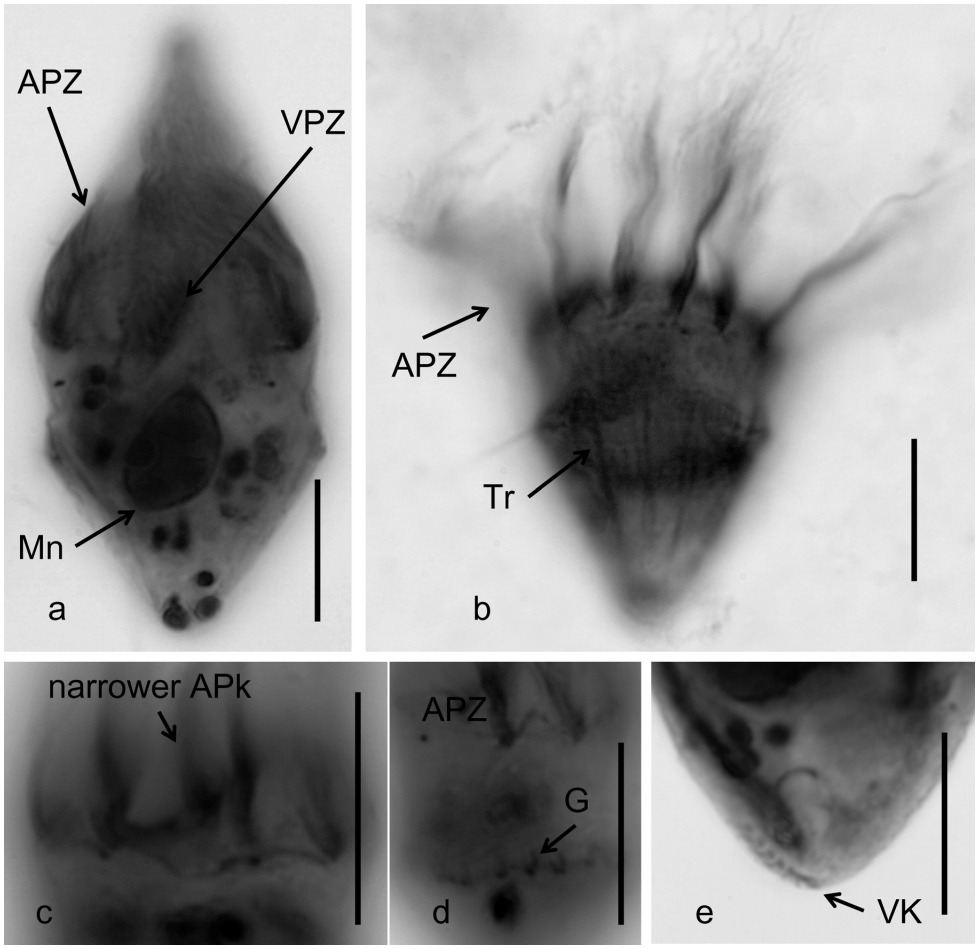

Fig. 20. Microphotographs of protargol-stained *Strombidium* cf. *taylori.* a, ventral view showing anterior polykinetid zone (APZ) with tapering anterior polykinetids, ventral polykinetid zone (VPZ) and a macronucleus (Mn); b, dorsal view showing trichites (Tr) and APZ with fanwise anterior polykinetids; c, oral area showing a narrower anterior polykinetid (APk) located beside the left margin of the oral groove; d, equatorial area showing APZ and girdle (G) composed of dikinetids with the single kinetosome ciliated; e, ventral kinety (VK) composed of dikinetids with the single kinetosome ciliated. Scale bar: 10 µm.

ventral polykinetid number (10–14 vs. 12–15) and macronucleus shape ("U"-shaped). This population, however, has a different arrangement of the APZ and VPZ (distinctly separated vs. not distinctly separated), different style in girdle kinety (dikinetids with the single kinetosome ciliated vs. monokinetids with short cilia) and a different number of girdle kinetids (20–30 vs. more than 40 estimated from figures). From these inconsistencies, this species could not be identified undoubtedly as *Strombidium taylori* in the present study.

Class Litostomatea Small & Lynn, 1981
Subclass Haptoria Corliss, 1974
Order Cyclotrichida Jankowski, 1980
Family Mesodiniidae Jankowski, 1980
Genus *Myrionecta* Jankowski, 1976
***Myrionecta rubra* (Lohmann, 1908) Jankowski, 1976 (Figs 21 & 22)**

Halteria rubra Lohmann, 1908: 303–304, pl. 17, figs 37–41.
Mesodinium rubrum Hamberger & Buddenbrock, 1911: 26, fig. 20; Taylor et al., 1971: 397–400, figs 3–7; Lindholm, 1985: 7–16, figs 4–8.
Myrionecta rubra Jankowski, 1976: 168; Petz, 1999: 291–292, fig. 8.13; Petz, 2005: 411, figs 14.108a–b, 14.164.

Description. Cell ovoid, composed of larger anterior and smaller posterior semispherical parts, 10–14 µm (mean = 11.7 µm, n = 10) in length and 7–10 µm (mean = 7.8 µm, n = 12) in width. Two ovoid macronuclei (Mn), 1.5–3.0 µm (mean = 1.8 µm, n = 12) in diameter, located in the posterior part. One symbiont cryptophyte nucleus (SCN) with nucleolus, 2–3 µm in diameter, sometimes observable clearly near Mn. Symbiont chloroplasts (SC), 2–7 nos. (mean = 3.3 nos., n = 12), mainly positioned in the anterior part. Equatorial kinety belt (EKB) composed of 18–23 longitudinal kinety rows (mean = 19.8 rows, n = 12) with basal row length of 1.5–2 µm. Pre-equatorial kinety belt (PKB) composed of the same row number as observed in EKB with basal row length of about 1.0 µm.

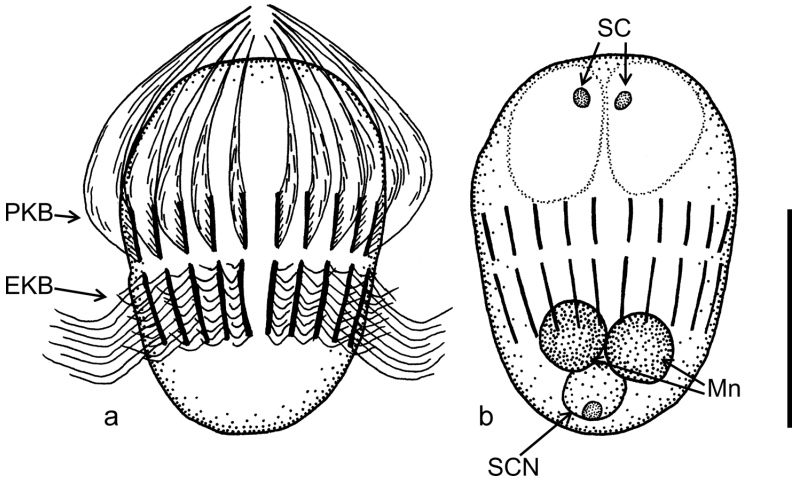

Fig. 21. Schematic figures of protargol-stained *Myrionecta rubra*. a, lateral view showing pre-equatorial kinety belt (PKB) and equatorial kinety belt (EKB); b, lateral view showing two symbiont chloroplasts (SC), two macronuclei (Mn) and one symbiont cryptophyte nucleus (SCN). Scale bar: 5 µm.

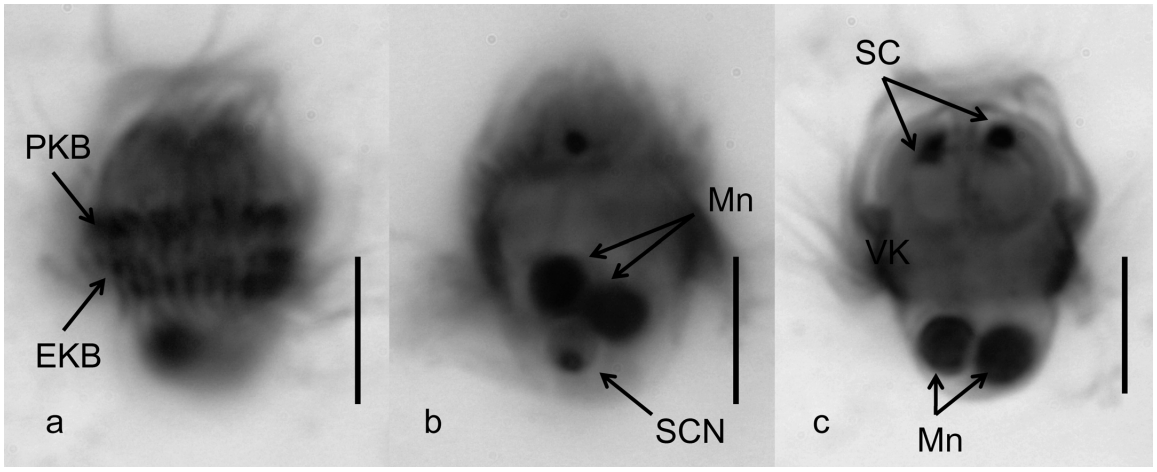

Fig. 22. Microphotographs of protargol-stained *Myrionecta rubra*. a, lateral surface view showing equatorial kinety belt (EKB) and pre-equatorial kinety belt (PKB); b, lateral transect view showing two macronuclei (Mn) and one symbiont cryptophyte nucleus (SCN); c, lateral transect view showing two symbiont chloroplasts (SC) and two Mn. Scale bar: 5 µm.

Remarks and comparisons. Although the Franklin-Bay population is very similar to the general description (Strüder-Kypke et al. 2001–2002), it is remarkably biased towards being smaller in body size (10–14 µm vs. 10–70 µm in length). Probably hence, it exhibited a tendency towards fewer symbiont chloroplasts (2–7 vs. many) and EKB (or PKB) kinety rows (18–23 vs. 20–80), and a different macronucleus position (posterior part vs. central part).

The genus *Myrionecta* was initially proposed for *Mesodinim* forms that lack oral tentacles (Jankowski 1976, Small & Lynn 1985). This criterion however was not widely accepted, because oral tentacles are easily lost and possession of them was recognized in many populations even if it was rare (Lindholm et al. 1988, Crawford 1989). Thereafter Krainer & Foissner (1990) proposed new keys to the genus *Myrionecta*; cell form (anterior portion larger than posterior) and PKB kinety (seemingly composed of dikinetids) are criteria in distinguishing *Myrionecta* from *Mesodinium*. After this proposal, the name *Myrionceta rubra* has been gradually accepted (e.g. Petz 1999, Lynn & Small 2000), while the change in nomenclature is sometimes debated owing to great variation in cell morphology (Crawford & Lindholm 1997).

Distribution. Geographical distribution of this species is extremely wide, extending from the polar seas to equatorial waters (e.g. Taylor et al. 1971, Petz 1999, Petz 2005). Even in Antarctic saline lakes (Gibson et al. 1997) and in the polar sea-ice (Lizotte 2003), this species is one of the dominant autotrophs. It occurred at 1,200 cells L^{-1} and was predominant (50%) among the planktonic ciliates; hence, it might play an important ecological role below the sea ice in Franklin Bay.

Acknowledgments

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