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Protozoan ciliate epibionts on the freshwater shrimp Caridina (Crustacea, Decapoda, Atyidae) from the Malili lake system on Sulawesi (Indonesia)

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Protozoan ciliate epibionts on the freshwater shrimp *Caridina* (Crustacea, Decapoda, Atyidae) from the Malili lake system on Sulawesi (Indonesia)

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Abstract

Protozoan ciliate epibionts on the freshwater shrimp *Caridina* (Decapoda, Atyidae), in particular from the ancient Malili lake system on Sulawesi (Indonesia), were studied. These ciliates belong to the following genera: the suctorians *Acineta*, and the peritrichs *Thuricola*, *Cothurnia*, *Vorticella*, *Opercularia*, and *Zoothamnium*. The ciliates were located on diverse areas of the surface and appendages of the shrimp. Morphological and taxonomical data of these ciliates are described, as well as the general distribution of each species on the basibiont. This is the first time that these ciliate epibiont species have been described on shrimps of the genus *Caridina*, where formerly only a suctorian of the genus *Spelaeophrya* has been found as an epibiont. Special features of the epibiont species in comparison with the species previously described are indicated.

Keywords: *Caridina*, ciliate protozoans, *Cothurnia*, distribution, epibiosis, Malili lake system, *Opercularia*, taxonomic position, *Thuricola*, *Vorticella*, *Zoothamnium*

Introduction

Epibiosis is a non-symbiotic, facultative, and interspecific association, whereby one organism lives on the surface (epibiont) of another organism (basibiont) (Wahl 1989; Wahl et al. 1997). This association can be temporary (Key et al. 1997) or last for the entire lifespan of the organisms (Warner 1997; Buschbaum and Reise 1999). Many data on the biology and ecology of basibiont crustacean species can be obtained from the study of epibiosis (Bottom and Ropes 1988; Abelló et al. 1990; Abelló and Macpherson 1992; Gili et al. 1993).

Epibiosis involves a number of effects. They include advantages for the epibiont: dispersion, and commonly geographical expansion of the epibionts (Wahl 1989), increase in the supply of nutrients (Gili et al. 1993; Threlkeld et al. 1993), and protection against

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predation (Abelló et al. 1990). On the other hand, epibiosis can be disadvantageous for the epibiont: ontogenetic or behavioural changes of the basibiont (Wahl 1989; Threlkeld et al. 1993). Epibiosis can provide both mimetic protection for the basibiont (Ingle 1983; Maldonado and Uriz 1992) and cleaning (Bauer 1978). In contrast, epibiosis may have the disadvantage of restricting the mobility of the basibiont (Overstreet 1983), affecting growth and moulting (Glynn 1970; Reaka 1978), and the function of several organs (eyes, gills, appendages) (Johnson 1977; Overstreet 1987), an increase in anti-fouling activity of the basibiont (Zann et al. 1975), and an increase in the risk of predation (Willey et al. 1990). Epibiont and basibiont may compete for nutrients (Wahl 1989).

Among the protozoan ciliates, apostomatids, peritrichs, suctorians, heterotrichs, and chonotrichs have been described as epibionts on crustaceans (Collin 1912; Corliss 1979; Batisse 1986, 1992; Clamp 1991). The role of ciliates as epibionts on crustaceans has not been studied as thoroughly as that of other organisms, such as hydrozoans, bryozoans, and polychaetes (Sprague and Couch 1971).

With respect to suctorians, 38 genera are registered as epibionts on four classes of crustaceans: Branchiopoda, Maxillopoda, Malacostraca, and Ostracoda (Fernandez-Leborans and Tato-Porto 2000b). Suctorians may be facultative epibionts (on seaweed, submerged phanerogames, hydrozoans, bryozoans, tunicates, molluscs, and crustaceans) or specific epibionts. The kinetics of local water currents that carry food and oxygen is important in the distribution of the suctorians on their basibionts. For example, *Tokophrya* is located on the antennules of *Cyclops*, *Dendrocometes*, *Stylocometes*, and *Acineta* on the branchiae of gammarids, asellids, and decapods (respectively), and moreover, they avoid places on the host without strong water currents. Chemotactile stimuli lead the tomites to gregarious hosts, with long copulation or incubation periods, as in the case of amphipods (Batisse 1994).

There are 30 genera of peritrichs described as epibionts on five classes of crustaceans: Branchiopoda, Branchiura, Copepoda, Malacostraca, and Ostracoda (Fernandez-Leborans and Tato-Porto 2000a). There are peritrich epibionts, such as *Lagenophrys lunatus* Imamura, 1940 on *Palaemonetes*, that depend on their hosts for their food and that have adapted their life cycle to the moult cycle of their host (Clamp 1973). They have a free-swimming telotroch stage during their life cycle, and this larva settles and grows on an available surface that may be specific or not. Greater numbers of these larvae settle on rough surfaces than on smooth surfaces, and on thoracic appendages of crustaceans rather than on the carapace. Prerequisites for settlement by peritrichs could be: the hydrophylic nature of surfaces, a suitable chemical composition and the presence of protrusions or a roughness of the surface (Viljoen and Van As 1983). One of these genera, *Zoothamnium*, infested almost the entire zooplankton community (Valbonesi and Guglielmo 1988). *Zoothamnium* sp. usually attaches to the gills of shrimps because the gill bailer provides a constant flow of water across the gill surface, enabling the protozoans to feed on a steady current of bacteria, the principal diet of colonial peritrichs (Foster et al. 1978).

Caridina lanceolata Woltereck, 1937, *C. lingkonae* Woltereck, 1937, *C. loehae* Woltereck, 1937, *C. masapi* Woltereck, 1937, and *C. sp. 1*, Woltereck, 1937 (genus *Caridina* H. Milne Edwards, 1837; family Atyidae; order Decapoda) (Woltereck 1937a) are endemic freshwater shrimp in the ancient Malili lake system located in the central highlands of Sulawesi, Indonesia (Figure 1) (Woltereck 1937a, 1937b; Brooks 1950; Chace 1997; Y. Cai and D. Wowor, unpublished data; K. Zitzler and Y. Cai, unpublished data). The five connected Malili lakes harbour several endemic species flocks, such as the well-studied case of a viviparous snail radiation (Rintelen et al. 2004; Rintelen and Glaubrecht 2005), and

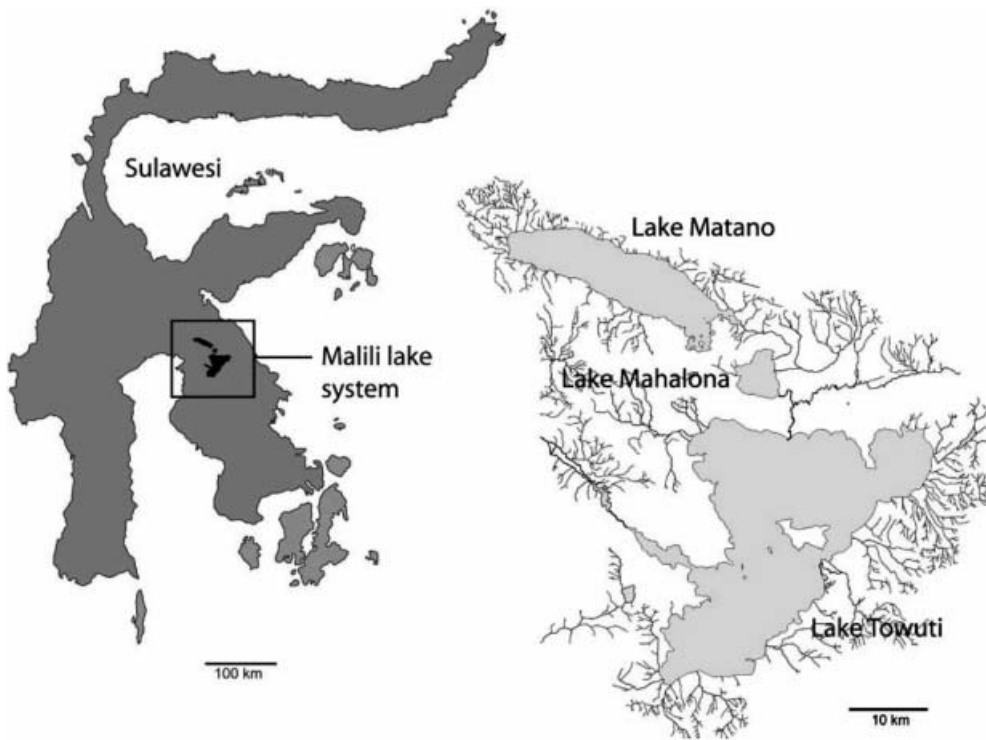


Figure 1. The Malili lake system on the Indonesian island of Sulawesi with its three main lakes: Lake Towuti, Lake Mahalona, and Lake Matano.

therefore represent a hotspot of species diversity. *Caridina lanceolata* is the only shrimp in the Malili lake system which is widely distributed throughout all three large lakes. It has a rather generalist feeding habit compared to other *Caridina* species in these lakes, for example *C. linkonae* and *C. loehae* (K. Zitzler, unpublished data) which have a tendency towards trophic specialization and local endemism. *Caridina lanceolata* was observed on several types of substrata, i.e. wood, plants, leaf litter, rocks in shallow and deep water (5–13 m depth), whereas *C. linkonae* and *C. loeha* were mainly pelagic and on rocks in shallow water, respectively.

Numerous specimens of *Caridina* collected in the Malili lake system and from two additional localities in South Sulawesi showed protozoan ciliate epibionts on their surface. The morphological features, biometrical characteristics, taxonomic position, as well as the location on the shrimp of these epibionts are described below.

Material and methods

The samples of *Caridina lanceolata*, *C. linkonae*, *C. loehae* and *C. sp. 1* were collected by the second author mainly from the largest lake, Lake Towuti, of the Malili lake system on Sulawesi, Indonesia (Figure 1), and *C. masapi* from a smaller lake, Lake Masapi, within the same system. Two other unidentified species, *Caridina sp. 2* and *C. sp. 3*, were collected from Tarrak River and from Bantimurung, South Sulawesi. All shrimp specimens were collected during fieldwork in 2003 and 2004. Samples were fixed in 95% ethanol and then transferred to 75% ethanol for light microscopy. In the laboratory,

shrimps were dissected and each anatomical unit was observed under a stereoscopic microscope.

For scanning electron microscopy (SEM) of the epibionts several shrimp specimens, fixed in 95% ethanol, were dehydrated in 100% ethanol for 30 min. Afterwards they were critical-point dried with a BAL-TEC CPD 030, mounted on aluminium specimen stubs with standard adhesive pads and coated with gold–palladium using a Polaron SC7 640 Sputter Coater. Pictures were taken on a LEO 1450VP Scanning Electron Microscope (software: 32 V02.03) at 10 kV.

Epibionts on the surface of the anatomical units of the shrimps were observed and counted under stereoscopic and light microscopy. In order to identify the protozoan epibionts, they were isolated and treated using the silver carbonate technique, according to the procedure described by Fernandez-Leborans and Castro de Zaldumbide (1986), and also with methyl green and neutral red. Measures of the epibionts were calculated using an ocular micrometer. Light microscope images were obtained using Image Analysis (KS300 Zeiss) and the diverse morphological features of the images were used to obtain the schemes of the epibiont species. Statistical analysis was performed using the programs Statgraphics and SPSS.

All epibionts examined are deposited in the Museum of Natural History, Berlin (ZMB, Museum für Naturkunde, Berlin, Germany—formerly Zoologisches Museum Berlin) (Table I).

Results

Ciliates of the genus Acineta

The ciliates were triangular in outline or bell-shaped and pedunculate. The length of the body ranged between 19.2 and 57.6 μm , and the width was 15.3–38.4 μm . The anterior part of the body contained two clearly distinguished actinophores on the corners, each supporting between 27 and 56 capitate tentacles. The macronucleus was rounded, 9.6–11.5 μm in diameter. The stalk had a length of 7.5–21.7 μm , and a width of 2.0–4.3 μm . The stalk showed longitudinal striations 12–18 in number. The striations in the base of the stalk were widely spaced. The basal disk was circular and thin, with a diameter of 5.6–8.9 μm (Tables I, II; Figures 2a, 3–5).

Taxonomic position. These epibionts belong to the genus *Acineta* Ehrenberg, 1833 (family Acinetidae Stein, 1859; order Endogenida Collin, 1912; subclass Suctorina Claparède and Lachmann, 1858; class Phyllopharyngea De Puytorac et al., 1974; phylum Ciliophora Doflein, 1901). As members of this genus, they had tentacles in two fascicles, with lorica and stalk (Lynn and Small 2000). The ciliate species most similar to the specimens found was *A. tuberosa*, Ehrenberg, 1833 since they had a bell- to Y-shaped body, laterally flattened, with two actinophores supporting capitate tentacles. The apical aperture was dumb-bell shaped. The stalk, variable in length, joined the lorica without collar or other structure. The spherical macronucleus was centrally located (Curds 1985).

Ciliates of the genus Thuricola

The ciliates were covered by an elongated and cylindrical lorica with an anterior opening with a diameter smaller than the maximum width of the lorica. The lorica was 32.6–38.4 μm

Table I. List of protozoan ciliate epibionts deposited in ZMB (Zoologisches Museum Berlin).

Taxon	ZMB number	Locality	Shrimp basibiont
<i>Acineta tuberosa</i>	3	Malili lake system, Lake Towuti, N shore	<i>Caridina</i> sp. 1
	4	Malili lake system, Lake Towuti, Loeha Island, S shore	<i>Caridina lanceolata</i>
	5	Malili lake system, Lake Towuti, E shore	<i>Caridina lanceolata</i>
	6	Malili lake system, Lake Towuti, W shore	<i>Caridina linkonae</i>
	7	Malili lake system, Petea River, between Lake Matano and Lake Mahalona	<i>Caridina loeha</i>
	8	Malili lake system, Lake Masapi	<i>Caridina masapi</i>
	9	South Sulawesi, Tarrak River, S of Enrekang	<i>Caridina</i> sp. 2
	10	South Sulawesi, Maros karst, Bantimurung	<i>Caridina</i> sp. 3
	11	Malili lake system, Lake Towuti, Loeha Island, S shore	<i>Caridina lanceolata</i>
	12	Malili lake system, Lake Towuti, E shore	<i>Caridina lanceolata</i>
<i>Cothurnia</i> sp.	13	Malili lake system, Lake Towuti, W shore	<i>Caridina linkonae</i>
	14	Malili lake system, Petea River, between Lake Matano and Lake Mahalona	<i>Caridina loeha</i>
	15	Malili lake system, Lake Masapi	<i>Caridina masapi</i>
	16	South Sulawesi, Maros karst, Bantimurung	<i>Caridina</i> sp. 3
<i>Opercularia</i> sp.	17	Malili lake system, Petea River, between Lake Matano and Lake Mahalona	<i>Caridina loeha</i>
	18	South Sulawesi, Maros karst, Bantimurung	<i>Caridina</i> sp. 3
<i>Thuricola</i> sp.	19	Malili lake system, Petea River, between Lake Matano and Lake Mahalona	<i>Caridina loeha</i>
<i>Vorticella</i> sp.	20	Malili lake system, Lake Towuti, Loeha Island, S shore	<i>Caridina lanceolata</i>
	21	Malili lake system, Petea River, between Lake Matano and Lake Mahalona	<i>Caridina loeha</i>
	22	South Sulawesi, Tarrak River, S of Enrekang	<i>Caridina</i> sp. 2
<i>Zoothamnium</i> sp.	23	Malili lake system, Lake Towuti, N shore	<i>Caridina</i> sp. 1
	24	Malili lake system, Lake Towuti, Loeha Island, S shore	<i>Caridina lanceolata</i>
	25	Malili lake system, Lake Towuti, E shore	<i>Caridina lanceolata</i>
	26	Malili lake system, Lake Towuti, W shore	<i>Caridina linkonae</i>
	27	Malili lake system, Petea River, between Lake Matano and Lake Mahalona	<i>Caridina loehae</i>
	28	Malili lake system, Lake Masapi	<i>Caridina masapi</i>
	29	South Sulawesi, Tarrak River, S of Enrekang	<i>Caridina</i> sp. 2

long and 19.2–24.9 μm wide. The aperture of the lorica had a diameter of 15.3–18 μm . An operculum that was located on the internal surface of the lorica characterized these ciliates. The operculum had a length of 10.9–14.3 μm . Inside the lorica, and noticeably smaller than it when retracted, the cellular body was located. Its length ranged between 19.2 and 28.8 μm , and its width between 11.5 and 23 μm . The macronucleus was located slightly above the equatorial zone of the body, and it was oval, 5.8–8 μm long, and 6.1–9.2 μm wide. The lorica attached directly on the surface of the crustacean, without stalk (Tables I, III; Figures 2b, 6).

Taxonomic position. These ciliates belonged to the genus *Thuricola* Kent, 1881 (family Vaginicolidae de Fromentel, 1874; order Sessilida Kahl, 1933; subclass Peritrichia Stein, 1859; class Oligohymenophorea De Puytorac et al., 1974; phylum Ciliophora Doflein, 1901). As peritrichs of this genus, they had a distinctive valve that closed obliquely when

Table II. Biometric features of *Acineta* sp. (measurements of fixed specimens in μm , $n=40$).

	Mean	SD	Minimum	Maximum
Body length	25.44	13.09	19.20	57.60
Body width	26.64	9.76	15.36	38.40
Macronucleus diameter	9.98	0.86	9.60	11.52
No. of tentacles per actinophore	38.00	12.08	27.00	56.00
Total no. of tentacles	70.00	21.35	58.00	102.00
Stalk length	13.9	7.84	7.56	21.74
Stalk width	2.85	3.5	2.01	4.32
Basal disc diameter	7.85	4.23	5.67	8.93
No. of stalk striations	14.3	3.45	12	18
Cyst body length	28.03	7.51	21.12	38.40
Cyst body width	16.51	3.21	11.52	19.20
Cyst lorica length	32.64	10.75	23.04	48.00
Cyst lorica width	22.56	1.84	21.12	24.96
Cyst macronucleus length	20.64	5.51	17.28	28.80
Cyst macronucleus width	6.72	1.11	5.76	7.68

the body was retracted. The lorica attached aborally without stalk (Lynn and Small 2000). The species most similar is *T. elegans* Biernacka, 1963, coinciding in the size of the body and macronucleus (Trueba 1980). However, *T. elegans* has been found in brackish water, while these ciliates were in freshwater environments.

Ciliates of the genus Cothurnia

They were loricated, without stalk. The lorica was narrow and elongated, measuring 67.2–96.0 μm long, and 19.2–24.9 μm wide. The individuals were attached aborally by the lorica, which was sharpened at this area. Between the lorica and the body or zooid, there was an endostyle. The opposite end contained the apical aperture, which was rounded, generally wider than the width in the middle zone. The apical aperture had a diameter of 20.9–25.7 μm . The retracted body occupied almost half of the lorica, and it was 34.5–57.6 μm long, and 13.4–19.2 μm wide. The macronucleus was ovoid, located in the anterior half of the body (12–15.1 μm long, 7.9–9.6 μm wide) (Tables I, IV; Figures 2c, 7–9).

Taxonomic position. These ciliates belonged to the genus *Cothurnia* Ehrenberg, 1831 (family Vaginicolidae de Fromentel, 1874; order Sessilida Kahl, 1933; subclass Peritrichia Stein, 1859; class Oligohymenophorea De Puytorac et al., 1974; phylum Ciliophora Doflein, 1901) (Lynn and Small 2000). As members of this genus, they were loricated peritrichs usually with one zooid per lorica. The lorica did not have valves or other means of closing the aperture. The inner layer or septum sometimes showed an enclosed space at the posterior end of the lorica (Warren and Paynter 1991). The ciliates found were characterized by the lack of a stalk, which is present in most species of *Cothurnia* described. The species most similar to these ciliates is *C. compressa* Claparède and Lachmann, 1858: the range of size is similar, as well as the presence of a short and broad endostyle, and the absence of a mesostyle. However, there were differences with respect to the stalk (short in *C. compressa*, absent in the ciliates found), the width of the lorica greater in *C. compressa*, and the size of the contracted zooid, also greater in *C. compressa*). In addition, *C. compressa* has been found in marine environments. For these reasons, these ciliates may represent a new species.

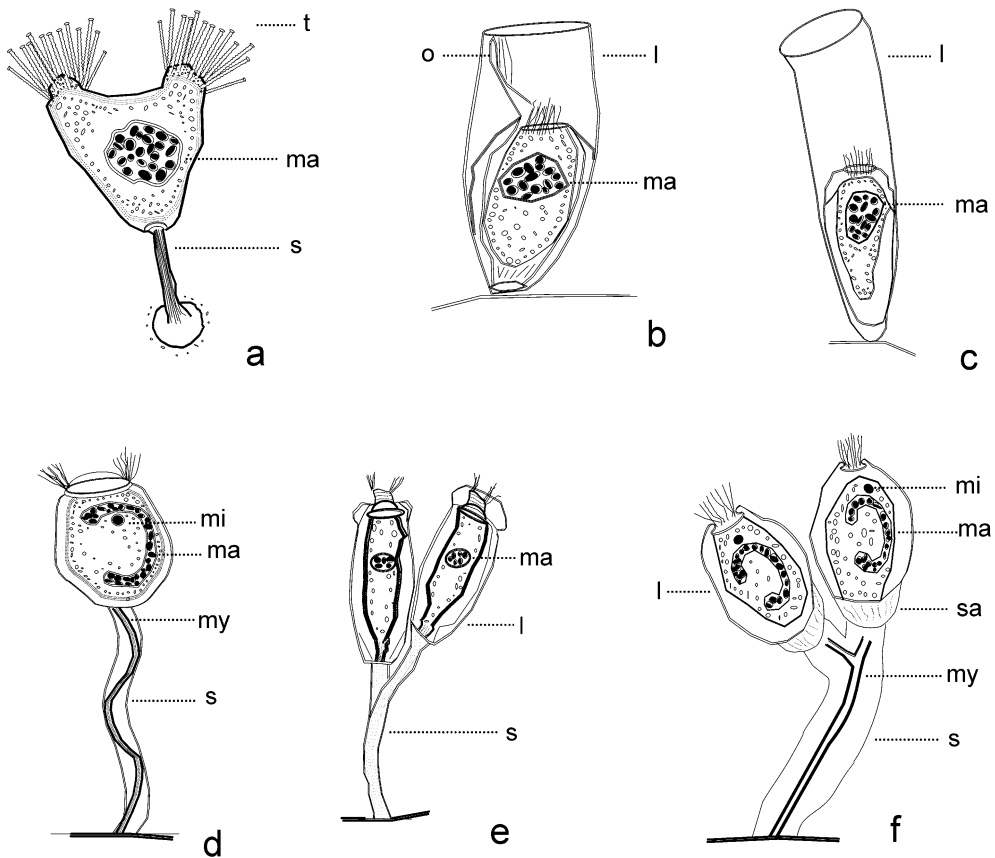


Figure 2. (a) *Acineta*; (b) *Thuricola*; (c) *Cothurnia*; (d) *Vorticella*; (e) *Opercularia*; (f) *Zoothamnium*. l, lorica; ma, macronucleus; mi, micronucleus; my, myoneme; o, operculum; s, stalk; sa, suprastylar area; t, tentacles.

Ciliates of the genus *Vorticella*

They were solitary and stalked ciliates. The body was bell-shaped, and more or less ovoid, contracted. It was 13.4–46 μm long, and 12.4–30.7 μm wide. The macronucleus was C-shaped and located longitudinally (13.5–16.7 μm long, 7.3–10.3 μm wide). The peristomial lip was shorter than the width of the body (11.1–14.9 μm diameter). The disc was convex and elevated on the peristome. The spherical micronucleus was located near the macronucleus. The stalk was elongated, 42.2–57.6 μm long, and 3.8–7.6 μm wide. The stalk contained a contractile myoneme along the whole of its length (Tables I, V; Figures 2d, 10).

Taxonomic position. These ciliates belonged to the genus *Vorticella* Linnaeus, 1767 (family Vorticellidae Ehrenberg, 1838; order Sessilida Kahl, 1933; subclass Peritrichia Stein, 1859; class Oligohymenophorea De Puytorac et al., 1974; phylum Ciliophora Doflein, 1901). As members of this genus, they are sessile and solitary, with a contractile stalk. The individuals were aloricate, without somatic cilia in the adult (Warren 1986; Lynn and Small 2000). The species most similar was *V. campanulata* (Kahl, 1933) Šramek-Hušek, 1948. It coincided in the size of the body and the shape of the macronucleus. However, it differed

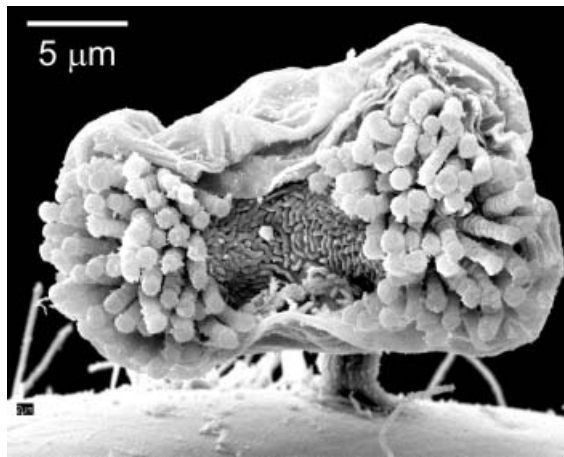


Figure 3. *Acineta*, view of the apical area with the tentacles (SEM).

from the present ciliates in the peristomial lip, which can be as wide as the body in *V. campanulata*, and in the disc, which is flat in *V. campanulata*.

Ciliates of the genus Opercularia

They were colonial peritrich ciliates. The stalk was ramified and non-contractile. The zooids had a thick external layer. The external shape was elongate and ovoid, 32.6–37.9 μm long and 15.3–23 μm wide. The body of the zooid was elongate, 26.8–30.7 μm long and 14.8–16.9 μm wide. The stalk was broad without myoneme (3.9–5.6 μm wide). In the anterior end of the body the peristomal disc protruded from the surface and appeared elevated from the margin of the body. It had a length of 3–4.7 μm, and a width of 4.7–6.8 μm. The macronucleus was oval and located in the middle area of the body

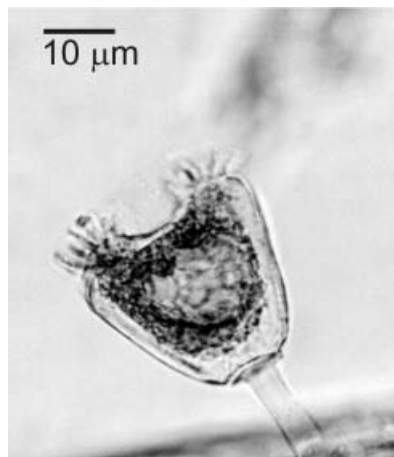


Figure 4. *Acineta*, lateral view showing the actinophores and the stalk.

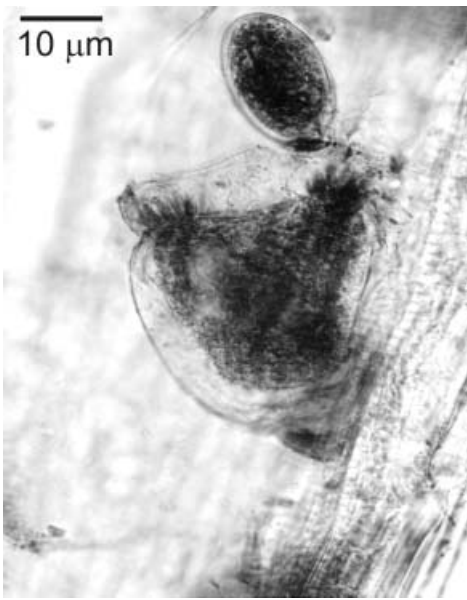


Figure 5. *Acineta*, a specimen with a larval stage in the apical surface.

(3.1–4.7 μm long, 6.8–8.9 μm wide). The posterior end of the body connected with the basal part of the lorica by a striated narrow zone. The number of zooids in the colony varied between one and eight (Tables I, VI; Figures 2e, 11).

Taxonomic position. The ciliates belonged to the genus *Opercularia* Goldfuss, 1820 (family Operculariidae Fauré-Fremiet in Corliss, 1979; order Sessilida Kahl, 1933; subclass Peritrichia Stein, 1859; class Oligohymenophorea De Puytorac et al., 1974; phylum Ciliophora Doflein, 1901). As members of this genus, the ciliates showed a peristomal disc on a stalk, having a furrow that separated and elevated the disc from the margin of the zooid. They were colonial, with straight peristome, with compact, rounded macronucleus. The zooids had a thick external layer (Lynn and Small 2000). The species most similar was *O. coarctata* (Claparède and Lachmann, 1858) Roux, 1901. They coincide in the size of the body and the shape and location of the macronucleus.

Table III. Biometric features of *Thuricola* sp. (measurements of fixed specimens in μm, n=40).

	Mean	SD	Minimum	Maximum
Body length	24.48	5.05	19.20	28.80
Body width	19.20	5.20	11.52	23.04
Lorica length	34.56	2.72	32.64	38.40
Lorica width	21.60	2.88	19.20	24.96
Apical aperture diameter	16.97	3.71	15.34	18.05
Operculum length	11.18	5.67	10.94	14.30
Macronucleus length	6.18	3.46	5.86	8.02
Macronucleus width	7.22	4.03	6.17	9.24



Figure 6. *Thuricola*, the zooid inside the lorica and the operculum.

Ciliates of the genus *Zoothamnium*

These peritrich ciliates were colonial, with the zooids linked by a ramified stalk, which contained a contractile myoneme. Each zooid was located within a thick external layer. The external shape was ovoid, elongated, 24.9–34.5 µm long and 15.3–28.8 µm wide. The body of the zooid was elongated, more narrow than the lorica (19.2–28.1 µm long, 12.8–18.2 µm wide). The macronucleus was C-shaped, and was 15.3–28.8 µm long and 5.7–9.6 µm wide. The micronucleus was disposed next to the macronucleus, and it was spherical with a diameter of 2.1–3.8 µm. The peristomal disc was short, being approximately half of the maximum body width (6.9–9.5 µm). The stalk was considerably broad in relation to the width of the cellular body, measuring 9.2–14.7 µm wide. This stalk was very diaphanous, showing a rounded contour. Inside the stalk was located the contractile myoneme (spasmoneme), with a width of 2–4.2 µm. The width of the stalk increased towards the base of the colony, where it was attached to the basibiont. In the colony, as a whole, the ramified stalk represented a relatively great volume. The stalk joined to the cellular body of the zooid by a cup-shaped structure. This suprastylar area was 4.1–6.2 µm in length, 10.3–14.8 µm in width, and showed a longitudinal striation (Tables I, VII; Figures 2f, 12).

Table IV. Biometric features of *Cothurnia* sp. (measurements of fixed specimens in µm, n=40).

	Mean	SD	Minimum	Maximum
Body length	44.64	7.59	34.56	57.60
Body width	16.56	2.04	13.44	19.20
Lorica length	82.56	10.76	67.20	96.00
Lorica width	20.64	2.24	19.20	24.96
Apical aperture diameter	23.89	3.78	20.98	25.77
Macronucleus length	13.03	2.28	12.06	15.14
Macronucleus width	8.69	2.12	7.92	9.61

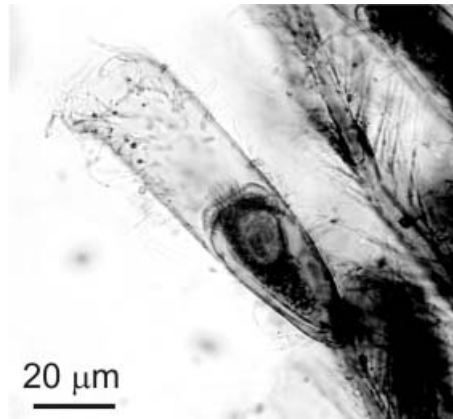


Figure 7. *Cothurnia*, an individual showing the lorica and the zooid.

Taxonomic position. These epibionts belonged to the genus *Zoothamnium* Ehrenberg, 1838 (family Vorticellidae Ehrenberg, 1838; order Sessilida Kahl, 1933; subclass Peritrichia Stein, 1859; class Oligohymenophorea De Puytorac et al., 1974; phylum Ciliophora Doflein, 1901). As members of this genus, they were colonial, the zooids shared continuous myonemes, and the entire colony was contractile (Lynn and Small 2000). The specimens observed were characterized by the thick external layer covering the zooids, the broad stalk and the suprastylar area between the stalk and the zooid, features infrequent among the common species of this genus. For these reasons, these ciliates might represent a new *Zoothamnium* species, although additional research on its morphology, especially on the infraciliature, is needed to confirm this possibility.

Distribution of the epibionts on Caridina

The general occurrence of epibionts on the examined shrimp taxa is shown in Table I. The distribution of each epibiont taxon attached to the different anatomical parts of all basibionts was observed as following: *Acineta* sp., *Cothurnia* sp., and *Zoothamnium* sp. were located on the rostrum, eyes, antennae, antennulae, pereopods, pleopods, uropods, and

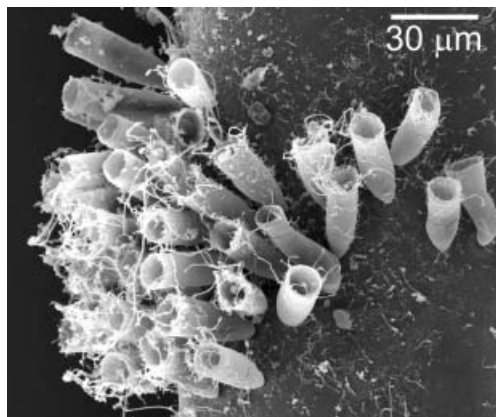


Figure 8. *Cothurnia*, arrangement of the individuals on the surface of the shrimp.

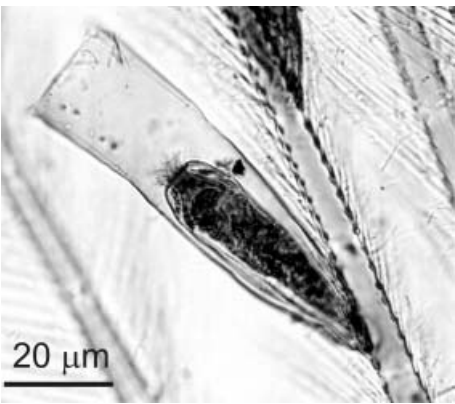


Figure 9. *Cothurnia*, view of the attachment of the ciliate to the surface of the basibiont.

telson. *Thuricola* sp. was located on the antennae, antennulae, uropods, and telson. *Vorticella* sp. was found on antennae, pereopods, and pleopods. *Opercularia* sp. appeared on the antennae, pereopods, pleopods, and uropods. *Acineta* sp. was the species with the highest density, followed by *Zoothamnium* sp. The genus with lowest density was *Vorticella* sp.

Discussion

The suctorian genus *Spelaeophrya* has been recorded as epibiont on species of the genus *Caridina* (Nei and Lu 1945). Other protozoan epibionts have not been described previously on the studied *Caridina* species. The suctorian genus *Acineta* has been found on a number of crustaceans: amphipods, decapods, cladocerans, ostracods, copepods, and isopods (Morado and Small 1995; Fernandez-Leborans and Tato-Porto 2000b). The peritrich genus *Thuricola* has not been found previously as epibiont on crustaceans. It has been described as epibiont on the seagrass *Thalassia testudinum* at Veracruz (Mexico) (Aladro-Lubel and Martínez-Murillo 1999). The peritrich genus *Cothurnia* has been described on several crustacean groups: ostracods, amphipods, decapods, copepods, amphipods, and isopods (Morado and Small 1995; Fernandez-Leborans and Tato-Porto 2000a), and recently on the marine tanaid *Halmyrapseudes spaansi* (Fernandez-Leborans and Sorbe 2003). The peritrich genus *Vorticella* has been described on isopods, amphipods, cladocerans, copepods, branchiopods, decapods, and isopods (Morado and Small 1995; Fernandez-Leborans and Tato-Porto 2000b), and on mysids (Precht 1935; Fernandez-Leborans 2004). The peritrich genus *Opercularia* has been found on decapods, ostracods,

Table V. Biometric features of *Vorticella* sp. (measurements of fixed specimens in μm, n=40).

	Mean	SD	Minimum	Maximum
Body length	27.36	12.26	13.44	46.08
Body width	21.36	5.07	12.43	30.72
Stalk length	49.92	10.86	42.24	57.60
Stalk width	5.76	2.72	3.84	7.68
Macronucleus length	15.36	2.86	13.56	16.78
Macronucleus width	9.60	3.01	7.31	10.34
Peristomial lip diameter	12.70	4.01	11.18	14.98

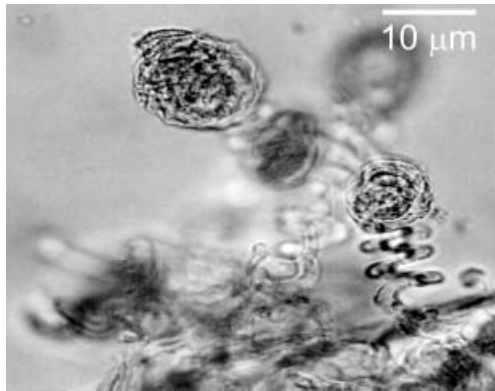


Figure 10. *Vorticella*, a specimen and its stalk.

isopods, copepods, and amphipods (Morado and Small 1995; Fernandez-Leborans and Tato-Porto 2000b). The peritrich genus *Zoothamnium* has been described on amphipods, isopods, decapods, and copepods (Morado and Small 1995; Fernandez-Leborans and Tato-Porto 2000b).

Apart from some species, such as *Thuricola* sp. that has not been found previously on crustaceans, the other epibionts on the observed shrimp species belonged to ciliate protozoan genera well known as epibionts on crustaceans. However, in the present study, several of these ciliates showed particular morphological characteristics which might be related to the special conditions of high endemism of organisms (e.g. atyid shrimps and pachychilid snails) in the Malili lake system, where most shrimps were collected. This was the case of the ciliates of the genus *Cothurnia* whose stalk was absent. Moreover, the peristomial lip and the disc shape of *Vorticella* were possibly particular anatomical details. The most noticeable data related to ciliates of the genus *Zoothamnium*, showing features such as the thick external layer, the remarkably broad stalk, and the conspicuous suprastylar area.

In natural environments ciliate epibionts rarely produce mortality in their crustacean basibionts. However, these epibionts can cause gill and surface fouling disease in shrimps at high densities, typically under stress conditions (Lightner 1996). In some cases, they become opportunistic pathogens in culture ponds during periods of low oxygen concentration (Johnson 1978). In aquaculture environments, with high crustacean

Table VI. Biometric features of *Opercularia* sp. (measurements of fixed specimens in μm , $n=40$).

	Mean	SD	Minimum	Maximum
Body length	28.16	1.57	26.88	30.72
Body width	15.55	2.62	14.87	16.90
Lorica length	34.08	0.96	32.64	37.91
Lorica width	19.84	0.33	15.36	23.04
Stalk width	4.80	0.81	3.99	5.61
Peristomial disc length	3.40	0.23	3.01	4.7
Peristomial disc width	5.11	0.89	4.72	6.80
Macronucleus length	3.8	1.31	3.15	4.72
Macronucleus width	7.24	1.46	6.84	8.92
No. of zooids in a colony	3.21	3.45	1	8



Figure 11. *Opercularia*, two individuals in their loricae.

densities, peritrich, suctorian, and scuticociliate species may cause significant mortalities (Morado and Small 1995). Some of the ciliate epibiont species found in the present study may cause mortality in crustaceans; it is the case in *Zoothamnium* sp. Densities of this epibiont on the gills of penaeid shrimp are directly correlated with the density of the basibiont (Overstreet 1973). Although this ciliate does not induce mortality, shrimp are so stressed that other disease elements can damage the populations (Boghen 1982; Johnson 1977). *Zoothamnium* sp. may affect the larval stages of *Eriocheir sinensis* Milne-Edwards 1853 (Wu and Feng 2004). The larvae infested were covered with a thick layer of whitish, hairy outgrowths. Most of them suffered a lack of ecdysis and halted development. Mass mortality occurred as the protozoan population developed (Wu and Feng 2004). *Zoothamnium penaei* Song, 1992 may represent a potential danger for cultured shrimps due to the high percentages of individuals infested by this epibiont (Vidal-Martinez et al. 2002). A high infestation of peritrich ciliates on the gills of decapods may affect respiratory

Table VII. Biometric features of *Zoothamnium* sp. (measurements of fixed specimens in µm, n=40).

	Mean	SD	Minimum	Maximum
Lorica length	29.76	2.90	24.96	34.56
Lorica width	21.60	4.56	15.36	28.80
Body length	25.24	3.24	19.27	28.16
Body width	15.59	2.18	12.87	18.22
Macronucleus length	19.20	6.46	15.36	28.80
Macronucleus width	6.72	1.92	5.76	9.60
Micronucleus diameter	2.22	0.97	2.18	3.89
Peristomial disc diameter	8.16	3.26	6.94	9.56
Stalk length	56.16	24.99	13.44	88.32
Stalk width	10.39	3.44	9.26	14.78
Stalk myoneme width	2.37	1.16	2.02	4.21
Suprastylar area length	4.45	2.18	4.17	6.26
Supastylar area width	12.78	4.02	10.39	14.85



Figure 12. *Zoothamnium*, several individuals of a colony.

and excretory functions (Couch 1967; Overstreet 1973). Other surveys indicated that, under aquaculture conditions, the density of the crustacean correlated with the density of the epibiont on the gills, and this fact was related to mortality, e.g. the peritrich ciliate *Lagenophrys* on the blue crab *Callinectes sapidus* Rathbun, 1896 (Couch 1966).

With regard to suctorian epibionts on crustaceans, the species *Ephelota gemmipara* (Hertwig, 1876) may cause mortalities of embryos of the European lobster *Homarus vulgaris* (Linnaeus, 1758) (Dannevig 1928, 1939; Morado and Small 1995), it may also be a stressing agent on heavily infested crustaceans, especially juveniles (Couch 1978; Gucatan et al. 1979; Fernandez-Leborans et al. 2005), as with other suctorians, e.g. *Ophryodendron mysidacii* Fernandez-Leborans, Tato-Porto and Sorbe, 1996 on the mysid *Schistomysis parkeri* Norman, 1892 (Fernandez-Leborans et al. 1996).

The epibionts may leave the basibiont due to moulting. For this reason, the protozoan epibionts may adapt their life-cycles in such ways as moulting-induced reproduction and formation of mobile stages (e.g. suctorian and peritrich ciliates), which are able to reinfest the basibionts (Overstreet 1987). The same genera of protozoans are located on different anatomical units of different genera of crustaceans. There is a specificity of locations of the protozoans on different crustacean hosts. Location of the protozoan on the host is specific and not random. The reasons for the specificity of protozoans for characteristic sites on their hosts are diverse and related to host habits. For example, water currents formed by the hosts that carry food particles are exploited by their epibionts (Morado and Small 1995).

Within the Malili lake system *Caridina lanceolata* represents a basibiont with the highest dispersal pattern among the endemic species flock of *Caridina*, and was observed on all kinds of substrata occurring in the lakes. Its high mobility within this lacustrine environment and its generalist feeding habit seems to provide many advantages for the epibionts. A promising future research aspect would be: (1) to investigate the epibionts' state of endemism and describe their taxonomy within the Malili lake system in detail (compared to riverine material from the rest of Sulawesi) such as has been done for pachychilid snails (Rintelen et al. 2004; Rintelen and Glaubrecht 2005); and (2) to

compare the density and biodiversity of epibionts found on *C. lanceolata* with those on other *Caridina* species in (and outside of) the Malili lake system, whose occurrence is limited to one or two lakes (local endemism) and which were observed to have habitat preferences (trophic specialization).

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