Food Selection of the Ciliated Protozoa, *Condylostoma vorticella* (Ehrenberg) in Lake Kasumigaura

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Abstract

The food selection of a herbivorous ciliated protozoa, *Condylostoma vorticella* (Ehrenberg) was examined in November 1980 in Takahamairi Bay of Lake Kasumigaura, using IVLEV's (1955) electivity index. This ciliated protozoa selectively fed on *Synechococcus*, *Kirchneriella*, *Dictyosphaerium*, *Coscinodiscus*, *Cryptomonas*, *Chlamydomonas*, and *Gomphosphaeria*, but rejected *Closterium*, *Phormidium*, *Synedra*, *Tetrastrum*, *Dactylococcopsis*, *Scenedesmus*, *Aphanizomenon*, *Melosira*, and *Micractinium*. The size and shape of algae were significant in the food selection, but the taxonomical groups were insignificant. The ciliate fed efficiently on food particles between 15 μm and 40 μm in size, but not filamentous and spindle-like algae or algae with long spines.

Colonies of *Microcystis* found most abundantly in this lake were preferably ingested by the ciliate. This ciliated protozoa is likely a significant link in the food chain between *Microcystis* and crustacean zooplankton.

1. Introduction

Ciliated protozoa are important in freshwater ecosystems not only as food links between bacteria and crustacean zooplankton (PORTER *et al.*, 1979) but also as an abundant component of zooplankton communities (PACE and ORCUTT, 1981). However, their role has often been ignored because of the difficulty in fixing and preserving samples for proper species identification. Also, there is no appropriate sampling method for determining the abundance and distribution of the protozoa. The density of ciliates in Lake Kasumigaura in November 1980 was 10^3 to $10^5 \cdot l^{-1}$, which was of the same order as reported in other eutrophic waters (BAMFORTH, 1958; SOROKIN and PAVELJEVA, 1972; PACE and ORCUTT, 1981). Therefore, ciliated protozoa should be considered an important component in this lake.

Selective feeding by ciliates was reported by CURDS (1977). Recently, HEINBOKEL (1978) and FENCHEL (1980 a, b) discussed the size of food particles consumed by ciliates. The present reporters investigated the food of the herbivorous ciliated protozoa *Condylostoma vorticella* (Ehrenberg), abundantly present in Takahamairi Bay,

and found that both the size of food particles and their shape have an influence on its feeding.

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2. Study Sites and Methods

This study was carried out at Takahamairi Bay in Lake Kasumigaura, a highly eutrophic body of water. Heavy blooms of *Microcystis* occur every summer and autumn in this lake. Water samples were taken from a 0.5 m depth by a Van-Dorn sampler on 7th, 10th, and 13th November 1980, when the water temperature was 13.0°C, 12.0°C, and 15.5°C, respectively. During the course of this study, dissolved oxygen varied from 10.3 to 16.9 ppm, pH from 7.3 to 9.2, and chlorophyll *a* from 108.4 to 136.8 $\text{mg} \cdot \text{m}^{-3}$. The concentration of ammonium nitrogen, nitrite plus nitrate nitrogen, and reactive phosphate, did not change much, ranging from 0.117 to 0.156 $\text{mg} \cdot l^{-1}$, from 1.178 to 1.289 $\text{mg} \cdot l^{-1}$, and from 0.004 to 0.007 $\text{mg} \cdot l^{-1}$, respectively (IWAKUMA *et al.*, 1982). Aliquot water samples of 100 ml were fixed immediately after sampling with Lugol's

iodine solution for identification and counting of phytoplankton by the UTERMÖHL method (UTERMÖHL, 1958) on the respective day. *Condylostoma vorticella* (Fig. 1) was sorted out from the other aliquot water samples by capillary pipettes under a binocular microscope within two to six hours after sampling, and the species and number of algae in ciliates were identified and counted under a microscope. A total of 101 individual ciliates were observed.

3. Results

Figure 2 shows the percentage composition of the algal species in *Condylostoma vorticella* and that in the natural water

Fig. 1. The photograph of the ciliate *Condylostoma vorticella* (Ehrenberg).

Fig. 2. The percentage composition of the algal species in *Condylostoma vorticella* (solid) and that in the natural water (open).

sample. Chrysophyceae (mostly *Chrysochromulina* and *Ochromonas*) and *Cyclotella* sp.1 were most numerous both in the ciliates and in the water sample. *Microcystis*, *Synechococcus*, *Cyclotella* sp.3, *Coscinodiscus*, *Kirchneriella*, *Dictyosphaerium*, and *Cryptomonas* were numerous in ciliates but scarce in the water sample. On the other hand, *Phormidium*, *Synedra*, *Scenedesmus*, and *Tetrastrum* were frequently encountered in the natural water, but only rarely in ciliates. These phenomena indicate that *C. vorticella* selectively feed on particular species of algae.

To evaluate the selection of algal species by *C. vorticella* IVLEV's (1955) electivity index ($E = (R - P) / (R + P)$) was used, where R was the proportion of the algal species taken in the ciliate and P the proportion of that species in the natural water. Table 1 shows the indices calculated for 36 taxa. *Condylostoma vorticella* rejected *Phormidium*, *Dactylococcopsis*, *Aphanizomenon*, *Synedra*, *Melosira*, *Closterium*, *Tetrastrum*, *Scenedesmus*, and *Micractinium*, and preferred *Synechococcus*, *Gomphosphaeria*, *Coscinodiscus*, *Kirchneriella*, *Dictyosphaerium*, *Chlamydomonas*, and *Cryptomonas*. No judgement could be made for the species that appeared less frequently in the water sample. Thus, the ciliate did not necessarily select specific taxonomical groups such as blue-green algae or diatoms.

The morphological characteristics and size of the algae seemed to be very significant factors in food selectivity. Filamentous algae such as *Melosira*, *Aphanizomenon*, and *Phormidium*, algae whose shape is spindlelike as in the case of *Closterium*, *Synedra*, and *Dactylococcopsis*, and those having long spines such as *Micractinium*, *Scenedesmus*, and *Tetrastrum* were apparently rejected. In the case of unicellular species, the larger species (15-30 micrometers long) such as *Coscinodiscus*, *Cryptomonas*, *Chlamydomonas*, and *Euglena* seemed to be consumed more frequently than the smaller species (5-7 micrometers long) such as *Cyclotella* sp.1, *Chrysochromulina*, and

Ochromonas. The ciliate could feed on colonies approximately 20-40 micrometers long which consisted of about 20 cells in the case of *Microcystis* and about 16 in the case of *Dictyosphaerium*.

4. Discussion

LEE *et al.* (1966) reported that foraminifera selected particular taxonomical groups such as diatoms and chlorophytes. In the case of the ciliate *Condylostoma vorticella*, the size and shape of algae were more significant in food selectivity than the taxonomical groups of the algae. In the present study, *Condylostoma vorticella* efficiently took algae of 15 μm to 40 μm . This seems to be consistent with FENCHEL's general conclusions (1980 a) that 14 species of ciliates each showed a distinct spectrum in the size of particles retained. As FENCHEL (1980 b, c, d) described, the range of particle size ingested by *C. vorticella* might be explained by the shape and size of the mouth of this species; food particles larger than 40 μm cannot enter the relatively smaller buccal cavity, and particles smaller than 15 μm passing between the adjoining membranes cannot be collected.

The ciliates did not feed on filamentous or spindlelike algae nor algae with long spines. McNAUGHT *et al.* (1980) showed that sheathed algae were not eaten by the copepod, *Diaptomus sicilis* and certain cyclopoids. However, the sheath of algae was insignificant for uptake by the ciliate, since *Synechococcus* and *Microcystis* were consumed to a considerable degree.

It has been reported that colonies or filaments of blue-green algae are not utilized by filter feeders (McMAHON and RIGLER, 1963; BURNS, 1968; PORTER, 1977). The bloom of *Microcystis* in Lake Kasumigaura has been explained by the lack of zooplankton which ingest colonies of this alga. YAMAMOTO (1978) found amoebatic protozoa which feed on *Microcystis*. The present investigators also found that *C. vorticella* also feed on *Microcystis*. Since BERK *et al.* (1977) and PORTER *et al.* (1979)

Table 1. Number of cells and percentage composition of algal species in *Condylostoma vorticella*, percentage composition of them in the water sample and IVLEV's electivity index.

	Number of cells counted in <i>Condylostoma vorticella</i>	Percentage composition in <i>Condylostoma vorticella</i>	Percentage composition in the water sample	IVLEV's electivity index
Blue-green algae				
<i>Anabaena</i> spp.	20	0.75	1.01	-0.15
* <i>Aphanizomenon flos-aquae</i>	3	0.11	0.56	-0.67
<i>Microcystis aeruginosa</i>	187	7.01	3.60	0.32
* <i>Gomphosphaeria</i> sp.	13	0.49	0.19	0.44
* <i>Phormidium tenue</i>	0	0	3.12	-1.00
<i>Synechococcus</i> sp.	181	6.79	0.21	0.94
<i>Dactylococcopsis</i> sp.	4	0.15	1.93	-0.86
Diatoms				
<i>Coscinodiscus</i> sp.	97	3.64	0.72	0.67
<i>Cyclotella</i> sp.1	415	15.57	23.17	-0.20
<i>Cyclotella</i> sp.2	4	0.15	0.30	0.33
<i>Cyclotella</i> sp.3	168	6.30	3.86	0.24
<i>Melosira</i> spp.	16	0.60	1.74	-0.49
<i>Synedra</i> spp.	18	0.68	14.76	-0.91
<i>Attheya</i> sp.	1	0.04	0.00	0.82
<i>Achnanthes</i> sp.	9	0.34	0.03	0.84
Attached algae	12	0.45	0.02	0.91
Green algae				
<i>Actinastrum</i> sp.	8	0.30	0.05	0.71
<i>Ankistrodesmus</i> sp.	1	0.04	0.03	0.14
<i>Kirchneriella</i> sp.	57	2.14	0.12	0.89
<i>Closterium aciculare</i>	0	0	0.56	-1.00
<i>Dictyosphaerium</i> sp.	397	14.89	2.43	0.72
<i>Mougeotia</i> sp.	0	0	0.07	-1.00
<i>Micractinium</i> sp.	8	0.30	1.15	-0.59
<i>Scenedesmus</i> spp.	24	0.90	7.54	-0.79
<i>Staurastrum</i> sp.	2	0.08	0.01	0.87
<i>Tetraedron</i> sp.	1	0.04	0.04	0.04
<i>Tetrastrum</i> sp.	4	0.15	2.88	-0.90
<i>Chlamydomonas</i> spp.	28	1.05	0.40	0.45
<i>Euglena</i> sp.	6	0.23	0.10	0.39
<i>Trachelomonas</i> sp.	1	0.04	0.02	0.45
*Green coccoidal	37	1.39	—	—
Chrysophyceae				
<i>Dinobryon</i> sp.	1	0.04	0.02	0.45
<i>Mallomonas</i> sp.	1	0.04	0.00	0.82
Others	536	20.11	46.12	-0.39
Cryptophyceae	372	13.95	3.46	0.60
Dinophyceae	2	0.08	0.02	0.57

*: Number of colonies or filaments instead of cells was counted for these algae.

*: Species could not be identified.

reported that ciliates were consumed by copepod, *Eurytemora* and cladoceran, *Daphnia*, it may be concluded that *C. vorticella* may be a significant link in the food chain between *Microcystis* and crustacean zooplankton in Lake Kasumigaura.

摘 要

霞ヶ浦高浜入で1980年11月に藻食性繊毛虫 *Condylostoma vorticella* (Ehrenberg) の食物選択性を調べた。食物選択性は、IVLEV (1955) の選択指数を用いて表わした。

選択性の高かった藻類は、藍藻の *Synechococcus*, *Gomphosphaeria*, 珪藻の *Coscinodiscus*, 緑藻の *Kirchneriella*, *Dictyosphaerium*, *Chlamydomonas*, クリプト藻の *Cryptomonas* であった。一方選択性の低かった藻類は、藍藻の *Phormidium*, *Dactylococcopsis*, *Aphanizomenon*, 珪藻の *Synedra*, *Melosira*, 緑藻の *Closterium*, *Tetrastrum*, *Scenedesmus*, *Micractinium* であり、この繊毛虫が、特定の分類群の藻類を好むという傾向は、認められなかった。

取り込まれやすい藻類のサイズは $15\mu\text{m}$ から $40\mu\text{m}$ であったが、この範囲内であっても糸状性の藻類および針状の棘を持つ藻類は、取り込まれにくいことがわかった。

藍藻の *Microcystis* の選択指数 ($=0.32$) は比較的高く、この繊毛虫が霞ヶ浦の生態系において *Microcystis* と浮遊性甲殻類の食物連鎖に重要な役割を果たしている可能性を窺知することができた。

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