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High Numbers of Testate Amoebae (Protozoa) in the Benthon of Clean, Acidified Mountain Streams

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Key words: Abundance; Biomass; Microzoobenthos; Protozoa; River acidification; Testacea; Testate amoebae

Summary

A simple method for the quantitative analysis of benthic testate amoebae communities in running waters is described. The method was applied to three Bavarian forest streams with contrasting pH regime: Eger (episodically acidified, mean pH 6.0), Röslau (periodically acidified, pH 5.2), Zinnbach (permanently acidified, pH 4.1). There were no pronounced differences in the number and kinds of species, though *Centropyxis elongata*, which prefers circumneutral environments, occurred only in the Eger, whereas *Trigonopyxis* sp., *Corythion* spp., and *Nebela* spp., which prefer acidic conditions, were more numerous in the heavily acidified Röslau and Zinnbach. The abundances and biomasses of the testaceans increased distinctly and gradually from the slightly acidified Eger (8125×10^3 ind./m^2, 0.31 g wet mass/m^2) over the moderately acidified Röslau (11250×10^3 ind./m^2, 0.61 g/m^2) to the heavily acidified Zinnbach (14531×10^3 ind./m^2, 1.32 g/m^2). Testate amoebae obviously react positively to acidification, i.e. increase in abundance and the dominance structure changes from small-sized to large-sized species. They might thus be valuable indicators for river acidification. Species richness and composition in the three streams were similar to those reported from other running waters. The most remarkable species found was *Edaphonobiotus campascoides*, previously known only from litter and soil. The quantitative data indicate that the contribution of the testate amoebae to the benthonic energy flow might be greater than hitherto assumed. This is supported by preliminary results showing up to 46250×10^3 testaceans/m^2 (1.48 g/m^2) in the sediment of a eutrophic river.

Introduction

Studies on river acidification have concentrated on algae, insect larvae and economically important fish. Whole-system experiments, mesocosm tests, and field surveys have demonstrated major shifts in species composition and decreases in species richness with increasing acidity. Sensitive species may be lost even at moderate levels of acidity, while acid tolerant species may appear or increase in abundance, resulting in little or no overall decrease in standing crop (BAKER & CHRISTENSEN 1991; LENHART & STEINBERG 1984; MUNIZ 1991; SCHÖNBORN 1992c).

Systematic field surveys on the effects of acidification on protozoan communities of running waters are sparse. Only LACKEY (1938, 1939) provided some valuable data from a survey of 200 sulfuric acid mine runs and pits in Virginia, Indiana, and Illinois (USA). Unfortunately, most heterotrophic protists were not determined to species level and testate amoebae were apparently excluded from the analysis. At or below pH 3.9, the number of species found in any given biotope was very small. The largest number was 11 at pH 2.6 and several samples showed no life on examination. All together, 11 genera of flagellates, 7 rhizopods, and 12 ciliate species were found in highly acid streams (pH $\leq$ 3.9); some occurred with high abundance, e.g. *Pleuromonas jaculans* and *Oxytricha* sp. The most frequently occurring species were *Euglena mutabilis*, naviculoid diatoms, *Chlamydomonas* spp., *Distyla* sp., *Actinophrys sol*, *Oxytricha* sp., *Ochromonas* sp., and *Ulothrix zonata*.

Experimental data are also rare and confined to short-term effects of rapid acidification (BICK & DREWS 1973; COSTAN & PLANAS 1986; NIEDERLEHNER & CAIRNS 1990). I thus conducted a field survey of some streams which have slowly and at varying degree acidified during the last decades, using testate amoebae as indicators. This group of protozoans is known to tolerate and even prefer acidic environments and has been frequently used to differentiate mull (circumneutral) and mor (acidic) humus (for review see FOISSNER 1987) as well as lake eutrophication (SCHÖNBORN et al. 1965) and organic river pollution (SLÁDEČEK 1981).

A second objective of this study was to provide river ecologists with reliable data on the abundance and biomass of benthic testate amoebae. Such data are extremely rare in the literature although many faunistic investigations are available.

Materials and Methods

1. Area description

The three streams (Eger, Röslau, Zinnbach) investigated are in the Fichtelgebirge, Bavaria, Germany, E 12° N 50°, whose highest elevation is 1053 m NN. The mountains are composed of young, base-poor granites containing comparatively high amounts of silicic acid. The spring of the Eger stream is situated in an area rich in phyllites, quartzites, and grey wackes; that of the Röslau stream in granitoid gneiss; that of the Zinnbach stream in granite. The Röslau and the Zinnbach are first and second-order tributaries, respectively, to the Eger which flows into the River Elbe (PONGRATZ 1991).

The drainage basin is primarily spruce forest. However, the region was almost completely deforested between 1920 and 1940 and used for agriculture and stock-farming; the Eger and Röslau streams were used for fish-farming.

Depositions of H^+, $SO_4^{2-}-S$, and NO_3^--N amount to 2–3.8, 53–73, and 11–13 kg/ha.a, respectively.

2. Study sites and physicochemical characteristics (Table 1)

The investigations were performed close downstream (up to 2.5 km) from the stream springs, ahead of any anthropogenous pollution and regulation. The physicochemical data are from PONGRATZ (1991) and ZAHN (1991).

Eger: Samples were taken about 1 km downstream from the spring, where the river bed was 0.5–1 m wide and strongly shaded, mainly by spruces. The water was about 20 cm deep and had a velocity of about 0.8 m/s. The run-off was thus estimated to be 20 and 40 l/s, respectively, at the two sampling occasions. The water was slightly brownish by humic materials, clear and had a delicious, sweetish taste. The river bed consisted of sand and coarse gravel, the surface of which was brownish and partially covered by liverworts. H_2S developed in the large, compact banks of spruce needles which accumulated in the lentic stream zones.

The Eger is episodically acidified. The pH is circumneutral during dry weather periods and decreases down to 4.4 after heavy rains and snow thaw. Sulfate, TOC and aluminium concentrations are distinctly lower than in the Röslau and Zinnbach streams. The comparatively slight acidification of the Eger is very likely caused by the flat drainage basin which enables prolonged contact of the rainwater with the surface soil and the rocky underground. Furthermore, the minerals in the spring region have a slightly higher buffer capacity than those found in the spring regions of the Röslau and Zinnbach streams.

Röslau: Samples were taken about 2.5 km downstream from the spring, where the river bed was 1.5–2 m wide and strongly shaded by spruces. Remnants of an old regulation were recognizable. The water was about 20 cm deep and had a velocity of about 0.8 m/s. The run-off was thus estimated to be 150–200 l/s, respectively, at the two sampling occasions. The water was slightly brownish by humic materials and clear. The river bed consisted of sand and stones which were covered by green filamentous algae (in spring) and liverworts. The lentic river zones were partially occupied by banks of spruce needles, while most of the fine sand was covered with a golden layer of *Synura* sp. and diatoms.

The Röslau is periodically acidified, i.e. the pH decreases in rainy and thaw periods to 3.9 and never approaches circumneutral conditions. Likewise, sulfate and aluminium concentrations show distinct fluctuations.

Zinnbach: Samples were taken about 500 m downstream from the spring, where the river bed was 0.2–0.4 m wide and strongly shaded by spruces. The water was about 5 cm deep and had a velocity of about 0.4 m/s. The run-off was thus estimated to be less than 10 l/s at both sampling occasions. The water was colourless, clear and tasty. The river bed consisted of sand and some gravel which was brownish and partially covered with liverworts. Some H_2S developed in the compact banks of spruce needles which accumulated in the lentic stream zones.

The Zinnbach is permanently acidified, i.e. the pH is always below 5. It also has higher concentrations of nitrate, sulfate and aluminium than the Eger and Röslau streams. The rather high level of organic carbon indicates that the spring is fed from a flat aquifer.

3. Sampling

Quantitative samples were taken in May (after thaw) and September 1992 in an about 200 m long part of each river. A 5 cm long steel corer with a diameter of 5 cm was rammed into the sediment to a depth of 2.5 cm and closed with a broad flexible spathula slipped between the corer and the sediment. The upper end of the corer remained open. The bottom half of the corer was thus filled with river sediment whereas the top half contained stream water.

Table 1. Physicochemical characteristics of the streams investigated (from ZAHN 1991). The data are averages from about 80 measurements each during the years 1983–1990. Extreme values in brackets.

Parameter	Streams		
	Eger (episodically)	Röslau (periodically)	Zinnbach (permanently acidified)
Mean flow (m^3)	0.031	0.103 (0.01–0.4)	0.008 (0–0.025)
pH	6.0 (4.4–7.0)	5.2 (3.9–6.6)	4.1 (3.4–4.9)
Conductivity (µS/cm)	53	49 (22–78)	87 (40–140)
TOC (mg/l)	2.3	4.6 (2–12)	4.4 (2.2–9.8)
$NO_3^- - N$ (mg/l)	0.73	0.69 (0.2–3)	1.4 (0.2–4.8)
SO_4^{2-} (mg/l)	5.4	15.0 (7–30)	25.9 (13–43)
Cl^- (mg/l)	8.3	2.4	3.0
Al_{tot} (mg/l)	0.21 (up to 1.3)	0.91 (0.1–2.1)	2.1 (0.6–3.8)

Twenty corers were taken at each site from the more obviously definable substrate types and thoroughly hand-mixed to a bulk sample consisting of about 1000 ml sediment and 1000 ml stream water. After short sedimentation to remove sand grains and gravel, 4 ml suspension were taken from the bulk sample with a large-bore (2 mm) pipette and mixed with 4 ml phenolic aniline blue to fix and differentiate full (live) and empty (dead) shells (AESCHT & FOISSNER 1992). Prior to counting, the sample was adjusted to 50 ml with distilled water. Testaceans were enumerated by direct microscopy of a 2 ml subsample as described in AESCHT & FOISSNER (1992), i.e. by placing the suspension dropwise on a slide.

4. Calculations

20 corers sampled an area of 400 cm^2 and contained a volume of 2000 ml. The dilution was 4:50 and 2 ml of the diluted sample were examined. The abundance per m^2 can thus be easily calculated. Remember, however, that numbers refer only to the upper 2.5 cm of the sediment, i.e. the depth to which the corer was rammed into the stream bed.

Biomasses were estimated according to the dimensions of the shells using three size classes (<50 µm, 50–100 µm, > 100 µm).

5. Identification of species, nomenclature

Species were identified using the specific taxonomic literature mentioned in AESCHT & FOISSNER (1989).

Results

A total of 60 testacean taxa were identified, 45 in the Eger stream, 43 in the Röslau stream, and 45 in the Zinnbach stream (Tables 2, 5).

Distinct differences in the number and kinds of species were not found. However, *Centropyxis elongata*, which prefers circumneutral conditions, occurred only in the Eger stream, whereas *Trigonopyxis* sp., *Corythion* spp. (s.l.), and *Nebela* spp., which prefer acidic conditions, occurred mainly in the heavily acidified Röslau and Zinnbach streams (Tables 2, 3). Dominant species were thus rather different in the streams investigated: *Centropyxis* spp. (Eger), *Edaphonobiotus campascoides* (Eger), *Difflugia* spp. (Zinnbach), *Euglypha* spp. (Eger, Röslau, Zinnbach), *Schoenbornia* spp. (Zinnbach), *Trachelocorythion pulchellum* (Röslau), *Trinema* spp. (Eger, Röslau, Zinnbach).

Abundances and biomasses showed pronounced differences (Tables 4, 5). The abundance in the heavily acidified Zinnbach stream was twice as high as in the slightly acidified Eger stream; biomass was even four times higher due to the occurrence of larger species (some voluminous *Difflugia* and *Nebela* species and a large *Euglypha*) in the Zinnbach (Table 4). Values for the periodically acidified Röslau were between those of the Eger and Zinnbach. There were no distinct differences in the proportion of full (alive cells) and empty shells (Table 5).

Table 2. Species found in the streams investigated. + full tests seen, – not found, * only empty tests seen.

Species	Streams		
	Eger	Röslau	Zinnbach
Arcella rotundata PLAYFAIR, 1917	–	+	–
Arcella sp.	*	–	–
Assulina muscorum GREEFF, 1988	*	*	*

Table 2. (Continued)

Species	Streams		
	Eger	Röslau	Zinnbach
Centropyxis aculeata (Ehrenberg, 1830)	+	–	–
Centropyxis aerophila Deflandre, 1929	+	*	*
Centropyxis aerophila sphagnicola Deflandre, 1929	+	+	+
Centropyxis elongata (Penard, 1890)	*	–	–
Centropyxis orbicularis Deflandre, 1929	*	–	*
Centropyxis plagiostoma Bonnet & Thomas, 1955	*	*	*
Centropyxis platystoma (Penard, 1890)	+	+	*
Centropyxis sylvatica Deflandre, 1929	–	*	*
Centropyxis sp.	–	*	–
Corythion delamarei Bonnet & Thomas, 1960	–	–	*
Corythion dubium Taranek, 1881	+	+	+
Cryptodifflugia oviformis Penard, 1890	–	–	+
Cyclopyxis eurystoma Deflandre, 1929	*	–	–
Cyclopyxis kahli Deflandre, 1929	–	*	–
Cyphoderia sp.	+	–	–
Difflugia globulosa (?) Dujardin, 1837	–	–	*
Difflugia lucida (?) Penard, 1890	+	+	+
Difflugia pyriformis Perty, 1849	+	+	+
Difflugia sp. I	+	*	+
Difflugia sp. II	+	+	+
Difflugia sp. III	+	–	–
Difflugiella sp.	*	*	–
Edaphonobiotus campascoides Schönborn, Foissner & Meisterfeld, 1983	+	+	*
Euglypha ciliata (Ehrenberg, 1848)	*	+	+
Euglypha compressa Carter, 1864	+	+	+
Euglypha filifera (?) Penard, 1890	–	–	+
Euglypha laevis Perty, 1849	+	+	+
Euglypha rotunda Wailes & Penard, 1911	+	+	+
Euglypha strigosa (Ehrenberg, 1871)	*	–	–
Euglypha strigosa glabra Wailes & Penard, 1911	*	*	*
Euglypha tuberculata Dujardin, 1841	*	*	+
Euglypha sp. I	–	–	+
Euglypha sp. II	*	–	–
Euglypha sp. III	–	–	*
Heleopera petricola Leidy, 1879	*	–	*
Hyalosphenia subflava Cash & Hopkinson, 1909	*	*	+
Nebela bohemica Taranek, 1881	*	*	+
Nebela militaris Penard, 1890	*	*	*
Nebela vitraea (?) Penard, 1899	–	–	+
Phryganella acropodia (Hertwig & Lesser, 1874)	*	*	+
Phryganella hemispherica (Penard, 1890)	*	*	*
Plagiopyxis declivis Bonnet & Thomas, 1955	*	*	*
Pseudodifflugia fascicularis Penard, 1902	–	*	–
Pseudodifflugia gracilis Schlumberger, 1845	*	*	*
Quadrulella symmetrica (Wallich, 1863)	–	*	–
Schoenbornia humicola (Schönborn, 1964)	+	*	+
Schoenbornia viscicula (Schönborn, 1964)	+	+	+
Sphenoderia fissirostris (?) Penard, 1890	+	*	+
Tracheleuglypha dentata (Penard, 1890)	*	*	*
Tracheleuglypha sp.	+	–	–
Trachelocorythion pulchellum (Penard, 1890)	*	+	+
Trigonopyxis arcula (Leidy, 1879)	*	+	*
Trigonopyxis minuta Schönborn & Peschke, 1988	-	*	*
Trinema complanatum Penard, 1890	*	*	*
Trinema enchelys (Ehrenberg, 1838)	*	+	+
Trinema lineare Penard, 1890	+	+	+
Trinema sp.	–	*	–
Valkanovia elegans (Schönborn, 1964)	*	+	+
Total number of taxa	45	43	45

Table 3. Individual numbers (m^2; means from two sampling occasions) of circumneutral (*Centropyxis* spp.) and acidophilic (*Trigonopyxis* sp., *Corythion* spp., *Nebela* spp.) testacean species in differently acidified streams [1].

Species	Streams		
	Eger (pH 6.0)	Röslau (pH 5.2)	Zinnbach (pH 4.1)
Centropyxis spp.	1700000	600000	600000
Trigonopyxis sp.	not found	300000	not found
Corythion spp. (s.l.)	500000	300000	600000
Nebela spp.	not found	not found	1000000

[1] Only full tests (active cells) were considered.

Table 4. Abundance of active testaceans in the benthon of three mountain streams at 08. 05. 1992 (upper line) and at 10. 09. 1992 (lower line).

Species	Streams (individuals/m^2)		
	Eger	Röslau	Zinnbach
Arcella rotundata	–	–	–
	–	312500	–
Centropyxis aculeata	937500	–	–
	625000	–	–
Centropyxis aerophila	312500	–	–
	312500	–	–
Centropyxis aerophila sphagnicola	625000	312500	625000
	312500	–	–
Centropyxis platystoma	–	–	–
	312500	312500	–
Corythion dubium	312500	312500	312500
	625000	–	937500
Cryptodifflugia oviformis	–	–	312500
	–	–	–
Cyphoderia sp.	–	–	–
	312500	–	–
Difflugia lucida (?)	625000	–	625000
	–	625000	312500
Difflugia pyriformis	–	–	1875000
	625000	312500	1250000
Difflugia sp. I	–	–	–
	312500	–	312500
Difflugia sp. II	–	312500	937500
	312500	–	625000
Difflugia sp. III	–	–	–
	312500	–	–
Edaphonobiotus campascoides	1562500	312500	–
	–	–	–
Euglypha ciliata	–	312500	312500
	–	–	–
Euglypha compressa	312500	312500	625000
	–	937500	625000
Euglypha filifera (?)	–	–	–
	–	–	312500
Euglypha laevis and *rotunda*	937500	937500	625000
	–	1562500	–
Euglypha tuberculata	–	–	–
	–	–	312500
Euglypha sp. I	–	–	2187500
	–	–	312500
Hyalosphenia subflava	–	–	312500
	–	–	–
Nebela bohemica	–	–	–
	–	–	312500

Table 4. (Continued)

Species	Streams (individuals/m^2)		
	Eger	Röslau	Zinnbach
Nebela vitraea (?)	–	–	–
	–	–	312500
Phryganella acropodia	–	–	625000
	–	–	312500
Schoenbornia humicola	312500	–	1562500
	–	–	625000
Schoenbornia viscicula	–	937500	937500
	625000	625000	312500
Sphenoderia fissirostris (?)	–	–	–
	625000	–	312500
Tracheleuglypha sp. (?)	–	–	–
	312500	–	–
Trachelocorythion pulchellum	–	–	–
	–	1562500	937500
Trigonopyxis arcula	–	–	–
	–	312500	–
Trinema enchelys	–	–	312500
	–	2187500	1875000
Trinema lineare	937500	1562500	3750000
	3750000	6875000	1875000
Valkanovia elegans	–	1562500	1250000
	–	–	–
Total abundance	6875000	6875000	17187000
	9375000	15625000	11875000

Table 5. Quantitative characteristics of the benthic testacean communities in three mountain streams. Values are averages from two sampling occasions and refer to the top 2.5 cm of the streambeds (cp. Table 4).

Stream	Total species number	Proportion of full and emtpy shells	Individuals/ m^2 ($\times 10^3$)	Biomass (g/m^2)*	Org. C (g/m^2)**	Energy (J/m^2)***	Respiration (ml $O_2/d/m^2$)****
Eger	45	1:6.7	8125	0.31	0.034	1564	131
Röslau	42	1:4.2	11250	0.61	0.067	3082	182
Zinnbach	45	1:5.3	14531	1.32	0.145	6670	235

* Wet mass.
** 1 μm^3 biovolume = 0.11 pg C (Foissner et al. 1992a).
*** 1 mg org. C = 46 J (Foissner et al. 1992a).
**** 0.6735 nl O_2/cell/h assumed (average of testacean species cited in Fenchel & Finlay 1983).

Discussion

1. Species composition

It is not widely known that a great number of testacean species live in streams and rivers, even forms rarely found elsewhere (De Groot 1979; Godeanu 1972; Opravilová & Štěpánek 1980; Štěpánek 1967; Živković 1975a, b). Godeanu (1971), for instance, reported 169 species from the Danube and some of its tributaries, and Opravilová (1974, 1977) found 85 and 101 taxa, respectively, in two Czech rivers.

In the present study, no attempts were made to identify all taxa to species level and "light-shelled" forms like *Pamphagus* and *Chlamydophrys* were not included in the analysis. Thus, only some aspects can be discussed. The most remarkable species found was *Edaphonobiotus campascoides*, previously known only from litter and soil (Schönborn et al. 1983). This species has a flat, circular pseudostome collar, possibly used to anchor the cell on substrate surfaces. Most of the species found have been recorded also from other European streams and rivers. Obviously, euryoecious species of the genera *Centropyxis*, *Difflugia*, *Euglypha*, and *Trinema* are usually frequent and contribute more than 50% to the testacean biomass (OPRAVILOVÁ 1980; ŠTĚPÁNEK 1967) although other species (e.g. *Pseudodifflugia* spp.) are sometimes more abundant (OPRAVILOVÁ 1977, 1983).

The increased occurrence of litter and soil species (*Nebela* spp., *Phryganella acropodia*, *Schoenbornia* spp.) in the very small Zinnbach is reasonable because of its close contact with the surrounding forest soil. OPRAVILOVÁ & ŠTĚPÁNEK (1980) also frequently found a terrestrial species, viz. *Pseudodifflugia senartensis*, in Czechoslovakian streams.

Biomasses increased more distinctly than abundances in the acidified streams, obviously due to a shift from small- to large-sized species (Table 5). The same has been reported by BEAVER & CRISMAN (1981) for ciliates of acidified lakes. These authors suggest that the changes were caused by changes in the available food.

2. The importance of testate amoebae in the energy flow of river sediments

Reliable data on abundances and biomasses of benthic testaceans in flowing waters are extremely rare. Often only relative measurements were applied, e.g. the number of specimens in 0.1 ml sediment (OPRAVILOVÁ 1974).

DSÜBAN-DECHTJAR (1966) counted 80000 (riverbed) to 300000 (muddy river bank) testaceans/m^2 (mainly *Difflugia* spp.) in the Danube delta. Even lower (2000 to 73000 individuals/m^2) numbers were found by LAMINGER (1974) in polluted parts of the Austrian Danube, where *Centropyxis* spp., *Cryptodifflugia penardi* and *Trinema enchelys* dominated. MADONI & GHETTI (1977) counted 80000 (clean station) to 2640000 (heavily polluted station) individuals/m^2 in the River Parma, Italy. However, they observed only three species (*Arcella vulgaris*, *Trinema lineare*, *Lecythium hyalinum*), indicating that the analysis was very incomplete or the sampling method was inadequate. BALDOCK et al. (1983) found 3100000 individuals/m^2 in a clean chalk stream in England, but provided no information on the species involved. These values are in the same order of magnitude as those found in the present study, especially when considering that MADONI & GHETTI (1977) and BALDOCK et al. (1983) investigated only the upper 1 cm sediment layer.

I can supplement these sparse data not only with the values shown in the present paper but also with unpublished results of a study performed in a mesosaprobic river near Munich (River Amper; description in FOISSNER et al. 1992b). The abundances and biomasses were obtained by a method similar to the one described in this paper and matches those found in the acidified streams very well, although on one occasion 46000000 testaceans/m^2 were registered (Table 6).

These data seemingly confirm the conclusion by OPRAVILOVÁ (1974) that testate amoebae are more abundant in streams than in rivers. However, the data basis is small and some of the values do not look very reliable; the quantitative methods used are often incompletely described or dubious and the numbers are frequently not related to a specific sediment depth.

SCHÖNBORN (1981, 1992a, b) showed that protozoans, especially ciliates, have a key role in one of the main energy flowpaths of the mesosaprobic River Saale, whereas testate amoebae are of minor importance. He found an annual mean density of 351000 individuals/m^2, which produced 1338 mg wet mass/m^2/y. Similar values were obtained by BALDOCK et al. (1983) in a clean chalk stream in England. However, SCHÖNBORN (1981) and BALDOCK et al. (1983) investigated only the periphyton. The present results and literature data (OPRAVILOVÁ 1980) suggest that the main portion of river testaceans lives in the sediment. Thus, their contribution to the protozoan energy flow is very likely considerably greater than hitherto assumed. Furthermore, considerable abundances of planktonic testaceans have been reported in slowly running rivers (BERECZKY 1979; GREEN 1963; KOFOID 1908; SABRI 1988).

Table 6. Quantitative characteristics of the benthic testacean communities in the river Amper at two sites and sampling occasions. Values refer to the top 5 cm of the riverbed (from FOISSNER, unpubl.).

Dates and sites	Individuals/m^2 ($\times 10^3$)	Biomass (g/m^2)*	Org. C (g/m^2)**	Energy (J/m^2)***	Respiration (ml O_2/d/m^2)****
Site A 11					
02. 04. 1992	46250	1.48	0.16	7360	748
04. 08. 1992	6875	0.33	0.04	1840	111
Site A 12					
02. 04. 1992	17500	0.69	0.08	3680	283
04. 08. 1992	6875	0.35	0.04	1840	111

* Wet mass.
** 1 μm^3 biovolume = 0.11 pg C (FOISSNER et al. 1992a).
*** 1 mg org. C = 46 J (FOISSNER et al. 1992a).
**** 0.6735 nl O_2/cell/h assumed (average of testacean species cited in FENCHEL & FINLAY 1983).

Unfortunately, biomass data are lacking from the macrozoobenthos of the streams investigated. It appears that the testacean biomasses in rivers and streams are one to two orders of magnitude lower than those commonly reported for the macrozoobenthos (for a comprehensive review see SCHÖNBORN 1992c). However, the biomass turnover of the microzoobenthos is much greater than that of the macrozoobenthos; SCHÖNBORN (1992a, b) reports P/B quotients between 17 (periphytic testaceans of the River Saale) and 207 (ciliates of the River Saale). Furthermore, the macrozoobenthos is often greatly depleted in heavily acidified rivers (for reviews see BAKER & CHRISTENSEN 1991; LENHART & STEINBERG 1984; MUNIZ 1991), and ciliates and flagellates are rare in clean streams. It is thus reasonable to speculate that under such conditions testate amoebae play a major role in the benthic energy flow, the more so as many of them can feed on plant detritus.

3. Testate amoebae as indicators of river acidification

Testaceans prefer acidic biotopes (SCHÖNBORN 1966). The reason is not exactly known, but probably they are weak competitors and profit from the exclusion of other organisms (SCHÖNBORN 1967). It was thus not too surprising to find the highest individual numbers in the stream with the lowest pH (Table 5). This seemingly contradicts results by COSTAN & PLANAS (1986), who observed a distinct reduction in the numbers and kinds of testate amoebae in acidified channels. However, in these experiments the pH was decreased rapidly from 7.1 – 6.1 to 4.1 – 3.9 and the community changes were followed for 72 hours only. Thus, these results, although impressingly showing that circumneutral testacean communities are almost extincted by rapid acidification, cannot be compared with field data from slowly acidified rivers where the organisms have plenty time to adapt and/or to invade from natural acidic biotopes which bear a rich and diverse protozoan fauna (FOISSNER 1980; GROLIÈRE 1977, 1978; MCGINNESS & JOHNSON 1992). The same applies to the experiments by BICK & DREWS (1973) on ciliates and by NIEDERLEHNER & CAIRNS (1990) on a natural protozoan community, although these tests were conducted over a three-week period. These results and LACKEY's (1938, 1939) field data provide distinct evidence that the taxonomic richness of circumneutral protozoan communities is severely affected at pH $\leq$ 5.3, while the gross function (algal and fungal biomass, net oxygen metabolism) of the whole system hardly changes even with severe acid stress.

The few field data available and the general knowledge on the biology of testate amoebae suggest that these protozoans have a high potential to indicate and monitor river acidification. Very likely, testate amoebae could supplement the benthic invertebrate "acidification index" proposed by RADDUM & FJELLHEIM (1984, 1986). To have a group of "positive" indicators could be of interest if the macrozoobenthos is sparse either due to natural reasons or too severe acidification.

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References

AESCHT, E. & FOISSNER, W. (1989): Stamm: Rhizopoda (U.-Kl.-Testacealobosia, Testaceafilosia). Catalogus Faunae Austriae Ia, 79 pp.

– (1992): Enumerating soil testate amoebae by direct counting. In: J. J. LEE & A. T. SOLDO (ed.), Protocols in protozoology, pp. B-6.1 – B-6.4. Lawrence, Kansas.

BAKER, J. P. & CHRISTENSEN, S. W. (1991): Effects of acidification on biological communities in aquatic ecosystems. In: D. F. CHARLES (ed.), Acidic deposition and aquatic ecosystems, pp. 83 – 106. New York, Berlin, Heidelberg, London, Paris, Tokyo, Hong Kong, Barcelona.

BALDOCK, B. M., BAKER, J. H. & SLEIGH, M. A. (1983): Abundance and productivity of protozoa in chalk streams. Holarct. Ecol. 6: 238 – 246.

BEAVER, J. R. & CRISMAN, T. L. (1981): Acid precipitation and the response of ciliated protozoans in Florida lakes. Verh. int. Verein. theor. angew. Limnol. **21**: 353 – 358.

BERECZKY, M. Cs. (1979): Gestaltung der Ciliata- und Testacea-Populationen der Donau unter der Einwirkung des Flussregimes und der Wasserkunstbauten zwischen Vác und Göd (Danubialia hungarica LXXXIX). Annls Univ. Scient. bpest. Rolando Eötvös **20 – 21**: 205 – 227.

BICK, H. & DREWS, E. F. (1973): Selbstreinigung und Ciliatenbesiedlung in saurem Milieu (Modellversuche). Hydrobiologia **42**: 393 – 402.

COSTAN, G. & PLANAS, D. (1986): Effects of a short-term experimental acidification on a microinvertebrate community: Rhizopoda, Testacea. Can. J. Zool. **64**: 1224 – 1230.

DE GROOT, A. A. (1979): Über einige wenig bekannten Rhizopoden. Hydrobiol. Bull. **13**: 34 – 49.

DSÜBAN-DECHTJAR, M. N. (1966): Rhizopoda im Kilija-Arm des Donau-Deltas. Soc. Int. Limnol., Colloquium Decennale Danubianum Bulgaria **10**: 1 – 7.

FENCHEL, T. & FINLAY, B. J. (1983): Respiration rates in heterotrophic, free-living protozoa. – Microb. Ecol. **9**: 99 – 122.

FOISSNER, W. (1980): Artenbestand und Struktur der Ciliatenzönose in alpinen Kleingewässern (Hohe Tauern, Österreich). Arch. Protistenk. **123**: 99 – 126.

– (1987): Soil protozoa: fundamental problems, ecological significance, adaptations in ciliates and testaceans, bioindicators, and guide to the literature. Progr. Protistol. **2**: 69- 212.

– BERGER, H. & KOHMANN, F. (1992a): Taxonomische und ökologische Revision der Ciliaten des Saprobiensystems –

Band II: Peritrichia, Heterotrichida, Odontostomatida. Informationsberichte des Bayer. Landesamtes für Wasserwirtschaft **5/92**: 1–502.
– Unterweger, A. & Henschel, T. (1992b): Comparison of direct stream bed and artificial substrate sampling of ciliates (Protozoa, Ciliophora) in a mesosaprobic river. Limnologica (Berlin) **22**: 97–104.
Godeanu, S. (1971): Date asupra ecologiei si răspîndirii geografice a testaceelor din zona viitorului lac de acumulare de la portile de fier. Studii Cerc. Biol. (Ser. Zool.) **23**: 479–486 (in Roumanian with French summary and English abstract).
– (1972): Espèces nouvelles de thécamoebiens (Protozoa, Rhizopoda, Arcellinida). Rev. Roum. Biol. **17**: 227–236.
Green, J. (1963): Zooplankton of the river Sokoto, the Rhizopoda Testacea. Proc. zool. Soc. Lond. **141**: 497–514.
Grolière, C.-A. (1977): Contribution a l'étude des ciliés des sphaignes: II. Dynamique des populations. Protistologica **13**: 335–352.
– (1978): Contribution a l'étude des ciliés des sphaignes III. Étude de mathématique des résultats. Protistologica **14**: 295–311.
Kofoid, C. A. (1908): Plankton studies. V. The plankton of the Illinois river, 1894–1899. Part II. Constituent organisms and their seasonal distribution. Bull. Ill. St. Lab. nat. Hist. **8**: 3–17.
Lackey, J. B. (1938): The flora and fauna of surface waters polluted by acid mine drainage. Publ. Hlth Rep., Wash. **53**: 1499–1507.
– (1939): Aquatic life in waters polluted by acid mine waste. Publ. Hlth Rep., Wash. **54**: 740–746.
Laminger, H. (1974): Ein Beitrag zur Kenntnis der Protozoenfauna der Donau 1. Die Testaceen (Protozoa, Rhizopoda) im Abschnitt Obernzell–Linz (Oberösterreich). Arch. Hydrobiol. Suppl. **44**: 330–337.
Lenhart, B. & Steinberg, C. (1984): Limnochemische und limnobiologische Auswirkungen der Versauerung von kalkarmen Oberflächengewässern – eine Literaturstudie. Informationsberichte des Bayer. Landesamtes für Wasserwirtschaft, **4/84**, 203 pp.
Madoni, P. & Ghetti, P. F. (1977): Indagine preliminare sulla distribuzione dei ciliati e altri protozoi nei corsi d'acqua della val Parma. Rivista di Idrobiologia **16**: 35–53.
McGinness, S. & Johnson, D. B. (1992): Grazing of acidophilic bacteria by a flagellated protozoan. Microb. Ecol. **23**: 75–86.
Muniz, I. P. (1991): Freshwater acidification: its effects on species and communities of freshwater microbes, plants and animals. Proc. R. Soc. Edinb. **97B**: 227–254.
Niederlehner, B. R. & Cairns, J. Jr. (1990): Effects of increasing acidity on aquatic protozoan communities. Water, Air, Soil Pollution **52**: 183–196.
Opravilová, V. (1974): Testacea (Protozoa: Rhizopoda) of the river Bobrava in Moravia. Věst. čsl. zool. Spol. **38**: 127–147.
– (1977): Microzoobenthos. In: M. Zelinka (ed.), Production conditions of the polluted trout brook, pp. 31–36. Folia Fac. Sci. Nat. Univ. Purk. Brun. **18** (Biologia 60): 1–105.
– (1980): Příspěvek k poznání ekologie krytenek (Rhizopoda, Testacea) potoka Bítýška (Morava, ČSSR). [A contribution to the ecology of Testacea of the Bítýška brook (Moravia, Czechoslovakia)]. Acta Sci. Nat. Mus. Morav. Occident. Třebíč **11**: 5–16 (in Czech with English summary).
– (1983): A contribution to the knowledge of Testacea (Protozoa: Rhizopoda) of the Jihlava river near Hrubšice. Scripta Fac. Sci. Nat. Univ. Purk. Brun. **13**: 23–32.
– Štěpánek, M. (1980): Some less frequent forms of Testacea (Protozoa: Rhizopoda) in small streams of the ČSSR. Věst. čsl. zool. Spol. **44**: 128–138.
Pongratz (1991): Chemische Beschaffenheit der versauerten Fließgewässer im Fichtelgebirge – langjährige Tendenz der Versauerung. Bericht Nr. 440–4428.6 an die Regierung von Oberfranken, 5 pp.
Raddum, G. G. & Fjellheim, A. (1984): Acidification and early warning organisms in freshwater in western Norway. Verh. Internat. Verein. theor. angew. Limnol. **22**: 1973–1980.
– (1986): Monitoring of acidification by use of stream invertebrates. Papier vorgestellt anläßlich der "Convention on long-range transboundary air pollution; Workshops on acidification of rivers and lakes", Grafenau (Germany), 28.–30. April 1986.
Sabri, A. W. (1988): Seasonal variation of testaceous amoebae (Sarcodina, Protozoa) population in the river Tigris. Arab. Gulf. J. Scient. Res., Agric. Biol. Sci. **B6**: 439–448.
Sládeček, V. (1981): Czechoslovak Rhizopoda and Actinopoda as indicators of saprobity. In: M. Sudzuki (ed.), Some approaches to saprobiological problems, pp. 1–8. Sanseido, Tokyo.
Štěpánek, M. (1967): Testacea des Benthos der Talsperre Vranov am Thayafluss. Hydrobiologia **29**: 1–66.
Schönborn, W. (1966): Beschalte Amöben (Testacea). A. Ziemsen, Wittenberg Lutherstadt.
– (1967): Taxozönotik der beschalten Süßwasser-Rhizopoden. Eine raumstrukturanalytische Untersuchung über Lebensraumerweiterung und Evolution bei der Mikrofauna. Limnologica (Berlin) **5**: 159–207.
– (1981): Populationsdynamik und Produktion der Testaceen (Protozoa: Rhizopoda) in der Saale. Zool. Jb. Syst. **108**: 301–313.
– (1992a): Comparative studies on the production biology of protozoan communities in freshwater and soil ecosystems. Arch. Protistenk. **141**: 187–214.
– (1992b): The role of protozoan communities in freshwater and soil ecosystems. Acta Protozoologica **31**: 11–18.
– (1992c): Fließgewässerbiologie. Jena.
– Flössner, D. & Proft, G. (1965): Die limnologische Charakterisierung des Profundals einiger norddeutscher Seen mit Hilfe von Testaceen-Gemeinschaften. Limnologica (Berlin) **3**: 371–380.
– Foissner, W. & Meisterfeld, R. (1983): Licht- und rasterelektronenmikroskopische Untersuchungen zur Schalenmorphologie und Rassenbildung bodenbewohnender Testaceen (Protozoa: Rhizopoda) sowie Vorschläge zur biometrischen Charakterisierung von Testaceen-Schalen. Protistologica **19**: 553–566.
Zahn, H. (1991): Sonderuntersuchung 80.6. Versauerung oberirdischer Gewässer. 1. Ergebnisbericht, Berichtszeitraum 1983–1990. Bayer. Landesamt für Wasserwirtschaft, 49 pp.
Živković, A. R. (1975a): Nouvelles et rares espèces de Testacea (Rhizopoda) dans la fauna de Danube. Bull. Mus. Hist. nat. Belgrade **30**: 119–123.
– (1975b): Contribution à la connaissance des espèces de genre *Protocucurbitella* Gauthier-Livre et Thomas dans la faune de Yougoslavie. Bull. Mus. Hist. nat. Belgrade **30**: 147–152.

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Buchbesprechung

Hartmut Bick: Ökologie. Grundlagen, terrestrische und aquatische Ökosysteme, angewandte Aspekte. IX + 335 S., 104 Abb., 20 farb. Tafeln, 24 Tab. Gustav Fischer Verlag: Stuttgart, Jena, New York 1993 Preis: Kart. DM 58,–, ÖS 453,–, SFr. 64,– ISBN 3-437-20503-X

Die Mehrzahl der deutschsprachigen Ökologie-Lehrbücher wurde von terrestrisch ausgerichteten Ökologen geschrieben, das vorliegende Buch von einem Limnologen. Mit ihm ist dann auch eine interessante Komplettierung des diesbezüglichen Lehrbuch-Angebotes gelungen, da der aquatische, vor allem limnische Lebensraum ausreichend berücksichtigt wurde. Behandelt werden der terrestrische, limnische und marine Lebensraum, aber auch die verschiedenen Disziplinen innerhalb der Ökologie werden vorgestellt, einschließlich der angewandten Aspekte.

Die Darstellungen verbleiben nicht in der allgemeinen Beschreibung ökologischer Vorgänge, sondern weisen auch die Organismen aus, die dafür verantwortlich sind, wovon ein 16 Seiten langes systematisches Register Zeugnis ablegt.

Das Buch bringt zunächst eine allgemeine Einführung in die Ökologie, behandelt dann die geographischen Grundlagen der Ökologie und schließlich monographisch die drei großen Ökoreiche: Land, Binnengewässer, Meer. Ein großes Kapitel ist der Angewandten Ökologie gewidmet. Kurze Einzelkapitel beschäftigen sich mit globalen Stoffkreisläufen, Produktionsvergleichen zwischen verschiedenen Ökosystemtypen und autökologischen Problemen. Das Buch bringt eine Fülle interessanter ökologischer Informationen und der nach einer Auskunft Suchende wird reich belohnt. Es ist für Studenten einschlägiger Disziplinen und Hörer von Einführungsvorlesungen in Ökologie zur Vertiefung ihrer Kenntnisse gedacht, kann aber darüber hinaus als generelle ökologische Informationsquelle gelten, wofür auch das ausführliche Literaturverzeichnis spricht.

Es ist ein Lehrbuch der Ökologie, das klassisches Grundwissen und moderne Erkenntnisse verarbeitet, eine breite Palette an Problemen vorstellt und terrestrische und aquatische Lebensräume gleichermaßen berücksichtigt (vielleicht mit Einschränkung für den marinen Raum). Viele gute Abbildungen und eine größere Zahl von Farbtafeln unterstützen den Text. Den großen Rahmen der Ökologie ohne Verzicht auf ausführliche konkrete Beispiele in einem für Studenten geeignetes Lehrbuch dargestellt zu haben, ist dem Autor vorzüglich gelungen. Jeder Student der Ökologie sollte sich dieses Buch beschaffen; auch der relativ geringe Preis kommt dem entgegen.

W. Schönborn, Jena