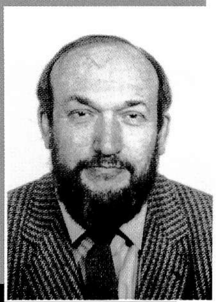
FACHTAGUNG

Biologische Gewässeruntersuchung und Bewertung; Taxonomie und Qualitätssicherung

Symposium zur Feier des 70. Geburtstages von Dr. Erik Mauch am 6. Oktober 2004 in Augsburg

REGIERUNG VON SCHWABEN



Prof. Dr. Wilhelm Foissner

was born in Austria on 18.08.1948. He studied zoology and botany at Salzburg University, where he became Professor in 1987. Professor Foissner and his group have published 12 books, more than 300 peer-reviewed papers, and got many prices. His monographs (the “Ciliate Atlas”) on the taxonomy and ecology of the ciliates used as bioindicators in the saprobic system, partially financed by the Bavarian government, made him famous also outside of his special field.

Protozoa as Bioindicators in Running Waters

Dedicated to Dr. Erik Mauch on the occasion of his 70th birthday

Summary

This article briefly reviews the knowledge on protozoa as bioindicators in streams and rivers. Pros and cons are discussed, showing that micro-organisms have several unique biological and bioindicative features. I argue that the separate calculation of saprobity indices for micro- and macro-organisms is contraproductive because it undermines the holistic approach of the saprobic system and does not take into account that reliable results need averaging of the different indicative properties of the various organism groups. The widespread neglection of micro-organisms in river quality assessment causes a large scale underestimation of organic pollution. Bioindication at species level is preferable, communities can give only a rough overview; some guidelines for ciliates are provided. Pressing research needs include taxonomic investigations of protozoa in clean and very clean lotic environments and studies on the ecological role of protozoa in clean and heavily polluted rivers.

Key words: ciliates, organic water pollution, research needs, saprobic system.

Introduction

Protozoa, especially ciliates are an important compartment in the organism set of the saprobic system, because most are bacteria feeders and thus become abundant under moderate and heavy organic pollution (Kolkwitz & Marsson 1902, Kolkwitz 1950, Liebmann 1962, Sladecek 1973, Mauch et al. 1985). Under such conditions, ciliates indicate even fine differences, for instance, small anaerobic islands in river beds and sewage plants and/or toxic influences. Further, nearly the same protozoan indicators can be used world-wide because most are cosmopolitans, at least morphologically.

In spite of these and other advantages, protozoa never became as common as benthic macro-invertebrates in pollution ecology and control. Many colleagues and pollution ecologists told me that they would like to use ciliates if they would have good identification literature. This stimulated us to produce several user-friendly keys (Foissner et al. 1991, 1992a, 1994, 1995, 1999, Foissner & Berger 1996, Berger & Foissner 2003), especially a detailed guide to the taxonomy and ecology of the micro-organisms used in the DIN-standard (Berger et al. 1997). Although these monographs, which contain together about 400 species used as bioindicators in rivers, lakes, and waste waters, are now widely used in scientific investigations, they hardly did change the view of pollution ecologists. Likewise, protozoa are not or only optionally included in national and international standards, for instance, the European Water Framework Directive (WFD). The present paper briefly reviews the knowledge on protozoa as bioindicators in lotic environments, emphasizing pros and cons and the problems produced by the separate calculation of a saprobic index for micro- and macro-organisms. Taxonomic resolution and research needs are discussed.

Protozoa as bioindicators in running waters: pros and cons

The pros and cons of using freshwater protozoa as bioindicators can be summarized as follows (based on Aescht & Foissner 1991):

1. Protozoa are an essential component in limnetic ecosystems, because of their large standing crop and production, especially in organically polluted sites (for reviews, see Foissner et al. 1992a, Schönborn 1992, Cleven 2004, Weisse 2004). Thus, changes in their abundance and community structure influence the nutrient cycles and the river's self-purification.

2. Protozoa, with their rapid growth and delicate external membranes, can react more quickly to environmental changes than any other eukaryotic organisms and can thus serve as an early warning system and excellent tool in bioassays (Nusch 1982, Nalecz-Jawecki et al. 2003).

3. The eukaryotic genome of protozoa is similar to that of metazoa. Their reactions to environmental changes can thus be related to higher organisms more convincingly than those of the prokaryotes.

4. Protozoa inhabit and are particularly abundant in those limnetic ecosystems that almost or entirely lack higher organisms due to extreme environmental conditions, e.g., in micro- and anaerobic sites (Liebmann 1962, Fenchel 1987) or in acidified rivers (Foissner 1994).

5. Protozoa are easily sampled (Blatterer 1995). In a comparative study, Foissner et al. (1992b) showed that simple "direct stream bed sampling" provides higher ciliate diversity than artificial substrate sampling which, additionally, underestimates the river's organic waste load.

Parameters	Sampling method		
	direct	foam	litterbag
Total number of [illegible]	174	122	150
Average number of [illegible] per sampling date	54.3	37.6	47.2
Average individual abundances	1.4	1.4	1.4
Average saprobity indices	2.7	2.5	2.6

There are, however, several factors that have apparently restricted the use of protozoa as bioindicators:

1. Most biologists dislike microscopic work, possibly because the instrument is more difficult to handle than a dissecting microscope. Further, protozoa are inconspicuous and usually invisible to the naked eye, making them unattractive to many potential investigators. In my experience, these are facts which cannot be changed, no even with perfect instruments and identification literature.

2. Many biologists believe that it is much more time-consuming to become familiar with protozoa than macro-invertebrates. However, this is not true. There are much more metazoan than protozoan indicator species (Sladecek 1973), and only about 200 of them are needed for successful practical work.

3. Enumeration of benthic micro-organisms is possibly more difficult and time-consuming than that of macro-invertebrates. However, reliable methods are now available (Cleven 2004).

Separate saprobic indices for micro-organisms and macro-invertebrates: a superfluous split undermining the holistic approach of the saprobic system

The saprobic system is a holistic approach, basically using indicator species from all main organism groups occurring in running waters (Kolkwitz & Marsson 1902, Kolkwitz 1950, Liebmann 1962, Mauch et al. 1985). This did not change when pollution was formalized in various semi-mathematical indices, which soon became widespread (Sladecek 1973). However, then the DIN-standard (1987, 1990) introduced the separation of the indices for micro- and macro-organisms. In my opinion, this was unfortunate because (i) it artificially splits a highly interwoven system; (ii) it favours a reductionistic view; (iii) it supports in some way those people who believe that micro-organisms are not needed in water quality assessment; (iv) I do not know of any convincing example that this split provides more correct results; and (v) the various groups of organisms have different biologies and indicative properties, i.e., are not, or usually are not, equivalent and replaceable (Aescht & Foissner 1991). Protozoa are an excellent example for this. Compared to the macro-invertebrates (i) they consume more food per mass unite; (ii) have a higher respiration rate per mass unite; (iii) have shorter generation and life times; and (iv) reproduce much faster.

Table 1: Ciliate species numbers, average individual numbers (ranked individual abundances divided by the number of species), and saprobity indices obtained with three sampling methods. The data are based on 14 samples each from six sites of two mesosaprobic rivers in Bavaria. From Foissner et al. (1992b).

Thus, the micro- and macroindex will always be different. This has been well documented by Blatterer (1995). He compared 11 rivers and showed that ciliates invariably indicate poorer water quality than diatoms and macro-invertebrates (Fig. 1). This is supported, inter alia, by data from Mauch (1990). Such results are to be expected! Many ciliates feed on bacteria and thus develop best in meso- and polysaprobic microhabitats, which occur also in clean rivers, for instance, around decaying plants and insect larvae.

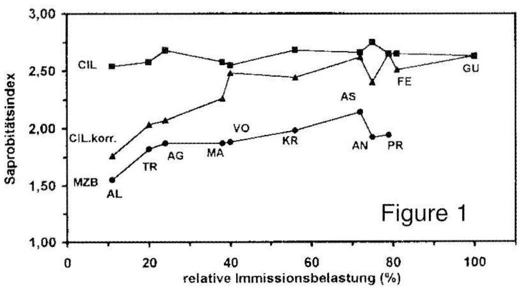


Figure 1

Figure 1: Comparison of saprobity indices obtained with ciliates (CIL) and macro-invertebrates (MZB) from 11 rivers in Upper Austria. "CIL. korr." is a corrected ciliate saprobity index. Rivers: AL – Alm, TR – Traun, AG – Ager, MA – Mattig, VO – Vöckla, KR – Krems, AS – Aschach, AN – Antiesen, PR – Pram, FE – Feldaist, GU – Gusen.

Accordingly, water quality assessment should include both, protozoa and macro-invertebrates. Together, they provide an accurate pollution measure (Kolkwitz & Marsson 1950, Liebmann 1962, Mauch et al. 1985, Berger et al. 1997).

Why are protozoa needed in quality assessment of running waters?

The evidences and ideas presented in the foregoing chapter have a serious consequence: organic pollution of running waters is underestimated if micro-organisms are not included in quality assessment. As this is, unfortunately, usually the case, most of our streams and are stronger polluted, probably by 0.2–0.5 saprobic units, than shown in the official maps. Certainly, this in the interest of various users, but harmful to the rivers, one of the most precious goods we have.

Taxonomic resolution needed

In applied ecology, taxonomic resolution is often limited by the lack of specialists and financial constraints. Further, national and international standards are frequently too low, that is, do not demand identification of species, although such data would be extremely useful in large river restauration and in the estimation of the influence of neozoons. Thus taxonomic education should be intensified at universities and museums, and taxonomists should be given a fair chance for a career.

As concerns ciliates, bioindication at species level is preferable. However, a reliable overview on pollution can be obtained also with ciliate communities (Foissner et al. 1994): oligosaprobity or beta-mesosaprobity prevails if there are relatively few species (< 25), of which none has an estimated abundance higher than 3 on a scale with six steps (1, 2, 3, 5, 7, 9), provided that sampling errors and toxic influences can be excluded. Beta- to alpha-mesosaprobity, alpha-mesosaprobity, or alpha- to polysaprobity prevail if there are many species (> 25), of which some fall into the abundance classes 3, 5 and /or 7. Finally, polysaprobity prevails, if there are relatively few species (< 25), of which some are numerous or very numerous (abundance classes 5, 7, and 9). This simple system is very practicable and reliable, especially if combined with a search for anaerobic protozoans at heavily or very heavily polluted sites: even if only few such specimens/species are found, they prove the occurrence of anaerobic islands.

Research needs

Lotic environments are the "classics" for assessing organic pollution with protozoan and metazoan bioindicators. Basically, applied ecological and taxonomic research has settled in this field and summarized in excellent reviews (Liebmann 1962, Sladecek 1973, Foissner et al. 1991–1995). However, there are still gaps in our knowledge, especially on the autecology of many indicator species.

Detailed studies are now in progress on the ecological role of protozoa in streams and rivers (Foissner 1994, Packroff & Zwick 1998, Weitere & Arndt 2003, Cleven 2004). These investigations confirmed and extended earlier results by Schönborn (1992) and others that protozoa are of great significance in carbon flow and nutrient cycling. However, few is known about the ecological role of protozoa in clean and very heavily polluted rivers.

Protozoa are excellent bioindicators at species and community level in heavily and very heavily polluted running waters, while few protozoan indicator species are known for clean rivers. However, a recent study indicates that such species exist (Fig. 2–4), but most of them are likely not yet described (Foissner 1997). Thus, more taxonomic research is needed on protozoa in clean and very clean rivers and streams.

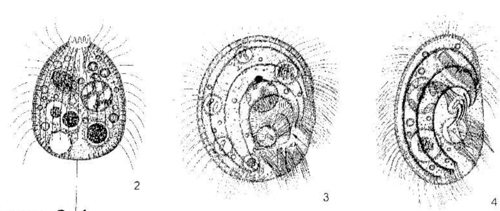


Figure 2-4

Figures 2–4: Oligosaprobic ciliate species from Bavarian rivers.
2: *Urotricha synuraphaga* Kahl, a small (25–40 × 20–30 µm) prostome ciliate, was re-discovered in a lentic site of the Röslau stream, where the sand was covered with a golden layer of *Synura* and diatoms.
3: *Hackenbergia langae* Foissner, a new genus and species, was discovered on submerged mosses from the Illach river. It is a small (25–35 × 18–25 µm), flat, almost circular ciliate, likely belonging to the class Colpodea.
4: *Pseudochlamydonella rheophila* Buitkamp, Song & Wilbert was re-discovered in the rivers Illach and Eger. It measures about 30 × 18 µm and likely belongs to the class Colpodea.

References

Aescht, E. and Foissner, W. (1991) Bioindikation mit mikroskopisch kleinen Bodentieren. *VDI-Berichte* 901, 985–1002.

Berger, H. and Foissner, W. (2003) Illustrated guide and ecological notes to ciliate indicator species (Protozoa, Ciliophora) in running waters, lakes, and sewage plants. In: Steinberg, Calmano, Klapper and Wilken (Eds.), *Handbuch Angewandte Limnologie.* Ecomed, Landsberg am Lech 17, 1–160.

Berger, H., Foissner, W. and Kohmann, F. (1997) Bestimmung und Ökologie der Mikrosaprobien nach DIN 38 410. G. Fischer Verlag, Stuttgart, Jena, Lübeck, Ulm.

Blatterer, H. (1995) Verbessertes Verfahren zur Berechnung des Saprobienindex mittels Ciliaten (Ciliophora, Protozoa). *Lauterbornia* 20, 23–36.

Cleven, E.-J. (2004) Seasonal and spatial distribution of ciliates in the sandy hyporheic zone of a lowland stream. *Europ. J. Protistol.* 40, 71–84.

DIN (Deutsches Institut für Normung e.V.) (1987) Deutsche Einheitsverfahren zur Wasser-, Abwasser- und Schlammuntersuchung. Biologisch-ökologische Gewässeruntersuchung (Gruppe M). Allgemeine Hinweise, Planung und Durchführung von Fließgewässeruntersuchungen (M1). *DIN* 38 410 (Teil 1), 1–13.

DIN (Deutsches Institut für Normung e.V.) (1990) Deutsche Einheitsverfahren zur Wasser-, Abwasser- und Schlammuntersuchung. Biologisch-ökologische Gewässeruntersuchung (Gruppe M). Bestimmung des Saprobienindex (M 2). *DIN* 38 410 (Teil 2), 1–18.

Fenchel, T. (1987) Ecology of Protozoa. The biology of free-living phagotrophic protists. Science Tech. Publishers, Madison.

Foissner, W. (1994) High numbers of testate amoebae (Protozoa) in the benthon of clean, acidified mountain streams. *Limnologica (Berlin)* 24, 323–331.

Foissner, W. (1997) Faunistic and taxonomic studies on ciliates (Protozoa, Ciliophora) from clean rivers in Bavaria (Germany), with descriptions of new species and ecological notes. *Limnologica (Berlin)* 27, 179–238.

Foissner, W. and Berger, H. (1996) A user-friendly guide to the ciliates (Protozoa, Ciliophora) commonly used by hydrobiologists as bioindicators in rivers, lakes, and waste waters, with notes on their ecology. *Freshw. Biol.* 35, 375–482.

Foissner, W., Blatterer, H., Berger, H. and Kohmann, F. (1991) Taxonomische und ökologische Revision der Ciliaten des Saprobiensystems – Band I: Cyrtophorida, Oligotrichida, Hypotrichia, Colpodea. *Informationsberichte des Bayer. Landesamtes für Wasserwirtschaft* 1/91, 1–478.

Foissner, W., Berger, H. and 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.

Foissner, W., Unterweger, A. and Henschel, T. (1992b) Comparison of direct stream bed and artificial sampling of ciliates (Protozoa, Ciliophora) in a mesosaprobic river. *Limnologica (Berlin)* 22, 97–104.

Foissner, W., Berger, H. and Kohmann, F. (1994) Taxonomische und ökologische Revision der Ciliaten des Saprobiensystems – Band III: Hymenostomata, Prostomatida, Nassulida. *Informationsberichte des Bayer. Landesamtes für Wasserwirtschaft* 1/94, 1–548.

Foissner, W., Berger, H., Blatterer, H. and Kohmann, F. (1995) Taxonomische und ökologische Revision der Ciliaten des Saprobiensystems – Band IV: Gymnostomatea, *Loxodes*, Suctoria. *Informationsberichte des Bayer. Landesamtes für Wasserwirtschaft* 1/95, 1–540.

Foissner, W., Berger, H., Schaumburg, J. (1999) Identification and ecology of limnetic plankton ciliates. *Informationsberichte des Bayer. Landesamtes für Wasserwirtschaft* 3/99, 1–793.

Kolkwitz, R. (1950) Oekologie der Saprobien. Über die Beziehungen der Wasserorganismen zur Umwelt. *SchrReihe Ver. Wass.- Boden- u. Lufthyg.* 4, 1–64.

Kolkwitz, R. and Marsson, M. (1902) Grundsätze für die biologische Beurtheilung des Wassers nach seiner Flora und Fauna. *Mitt. PrüfAnst. WassVersorg. Abwässerbeseit. Berl.* 1, 33–72.

Liebmann, H. (1962) Handbuch der Frischwasser- und Abwasser-Biologie. Biologie des Trinkwassers, Badewassers, Frischwassers, Vorfluters und Abwassers. Band I. 2nd ed. R. Oldenbourg, München.

Mauch, E. (1990) Der ökologische Zustand der Alb im Stadtgebiet von Karlsruhe und die Auswirkungen der Einleitung von Kühlwasser und Abwasser. *Limnologie aktuell* 1, 59–85.

Mauch, E., Kohmann, F. and Sanzin, W. (1985) Biologische Gewässeranalyse in Bayern. *Informationsberichte des Bayer. Landesamt für Wasserwirtschaft* 1/85, 1–254.

Nalecz-Jawecki, G., Grabinska-Sota, E. and Narkiewicz, P. (2003) The toxicity of cationic surfactants in four bioassays. *Ecotoxicology and Environmental Safety* 54, 87–91.

Nusch, E. A. (1982) Prüfung der biologischen Schadwirkungen von Wasserinhaltsstoffen mit Hilfe von Protozoentests. *Decheniana - Beihefte (Bonn)* 26, 87–98.

Packroff, G. and Zwick, P. (1998) The ciliate fauna of an unpolluted foothill stream, the Breitenbach, 2: quantitative aspects of the ciliates (Ciliophora; Protozoa) in fine sediments. *Europ. J. Protistol.* 34, 436–445.

Schönborn, W. (1992) Comparative studies on the production biology of protozoan communities in freshwater and soil ecosystems. *Arch. Protistenk.* 141, 187–214.

Sladecek, V. (1973) System of water quality from the biological point of view. *Arch. Hydrobiol. Beih. Ergebn. Limnol.* 7, i–iv, 1–218.

Weisse, T. (2004) Pelagic microbes – protozoa and the microbial food web. In: O'Sullivan, P. and Reynolds, C. R. (Eds.), *The Lakes Handbook* 1, 417–460.

Weitere, M. and Arndt, H. (2003) Structure of the heterotrophic flagellate community in the water column of the River Rhine (Germany). *Europ. J. Protistol.* 39, 287–300.