Limnologica 27 (3–4)
(1997) 271–280

LIMNOLOGICA

Centre for Environmental Research Leipzig–Halle, Project Area of Natural Landscapes, Leipzig, Germany

The Distribution of *Gammarus pulex* (L.), *Asellus aquaticus* L. and *Pisidium* sp. in an Acidified Forest Brook and Some Tributary Springs Indicating Problems in Assessing the Local State of Acidity at a Small Scale Level

CLAUS ORENDT & UDO REINHART

With 8 Figures and 2 Tables

Key words: Springs, brooks, acidification, assessment, pH tolerance, refuge

Summary

In this study the distribution of the acid-sensitive *Gammarus pulex, Asellus aquaticus* and *Pisidium* sp. in an acidified forest brook and its catchment area in Saxonia-Anhalt (Germany) was investigated. These organisms still build considerable populations in the circumneutral spring brooks which tribute to this brook. From there they apparently regularly immigrate into the main brook, where they can hardly survive because of the high acidity level. The populations of single tributaries are therefore isolated. Should the pH-level of the main brook be increased, e.g. by liming, a recolonization by these acid sensitive species could be expected from these refuges. This supports the important role of the non-acidified spring regions in forest ecosystems as regeneration potential of areas struck with such environmental impact.

1. Introduction

The acidification of lakes and streams in Central Europe by emissions of air-transported sulphuric and nitric acid can be noticed especially in the lower mountains but also more and more often in the lowlands. Much scientific research has been done about this phenomenon and its ecological consequences (e.g. BAUER et al. 1987; HEITKAMP & LESSMANN 1990; MATSCHULLAT et al. 1994; HOFMANN 1987; LEUVEN et al. 1987; MATTHIAS 1983; ORENDT & WEISSFLOG 1994). If a stream acidifies, only those organisms will survive that show a high resistance to the temporarily or permanently acidic milieu and its effects (e.g. increase of the aluminium concentration above toxic levels in the water). Often practical problems for pisciculture arise because many fish species show a high sensitivity to such changes in the milieu (BAUER et al. 1987; WEATHERLY & THOMAS 1989). This is also true for many macroinvertebrate species. Regular liming has often been used to buffer the excessive acid and to bring the waters to a circumneutral level. With such actions the theoretical possibility of the recolonization by acid-sensitive species is given. However, this can only be successful if enough refuges and non-impacted pathways exist from where the once indigenous species can recolonize the potential habitats.

Recently, a study on the benthic macroinvertebrates and epilithic diatoms coenoses of spring brooks in woodlands, situated east of the Leipzig–Halle–Bitterfeld area (Dübener und Dahlener Heide), a region of high industrial activity since the last century was conducted (ORENDT 1996; ORENDT, in prep.). According to NEUMEISTER et al. (1991) the highest deposition of acid and dust deriving from the chimneys of the industrial centres (combustion of brown coal) took place in the 70ies. ZIERATH (1981) recorded 383 kg/ha · a SO_4–S and 184 kg/ha · a calcium from the area of Bitterfeld for the years 1975 to 1979. In eastward direction, crossing the Dübener Heide Heathland, the amounts of depositions decreased with increasing distance from the emittent (128 kg/ha · a SO_4–S and 40 kg/ha · a calcium at Torgau/Elbe). The high amounts of calcium-rich dust neutralized the acid components (predominantly SO_2) near the emittent (Bitterfeld) causing a pH of 6.5 of the rain fallout. The rain fallout far from the emittent (Torgau) showed a lower pH (5.35) because the share of the basic components in the ash decreased. According to recent measurements of NIEHUS & BRÜGGEMANN (1995) near Bitterfeld the deposition of $SO_4{-}S$ and calcium dropped to 5% and 7% of the level of the 70ies measured by ZIERATH (l.c.), respectively, and at another site at the Dübener Heide to 29% and 13% of the level of the late 80ies (NIEHAUS & BRÜGGEMANN, l.c.), respectively.

These high amounts of acid and limy dust deposited in the investigated area lead to a particular pattern of acidification and liming effects in that area (see next paragraph). In this study an assessment of the state of acidity was performed for several investigated brooks using macroinvertebrate and epilithic diatom coenoses as well as the pH-level [according to BRAUCKMANN (1992) and HOFMANN (1994)]. In one investigated brook (Heidemühle) some acid-sensitive macroinvertebrate taxa (*Gammarus pulex, Asellus aquaticus, Pisidium* sp.) could be recorded. These indicated a much lower state of acidity ("episodically slightly acidic") compared to the assessment by the diatoms that was "permanently acidic". As several spring brooks tribute to the investigated brook, we assumed that acid-sensitive species were regularly imported from the spring brooks. Samples from these showed well developed population although there did not seem to be any decisively important difference in the habitat structure for these

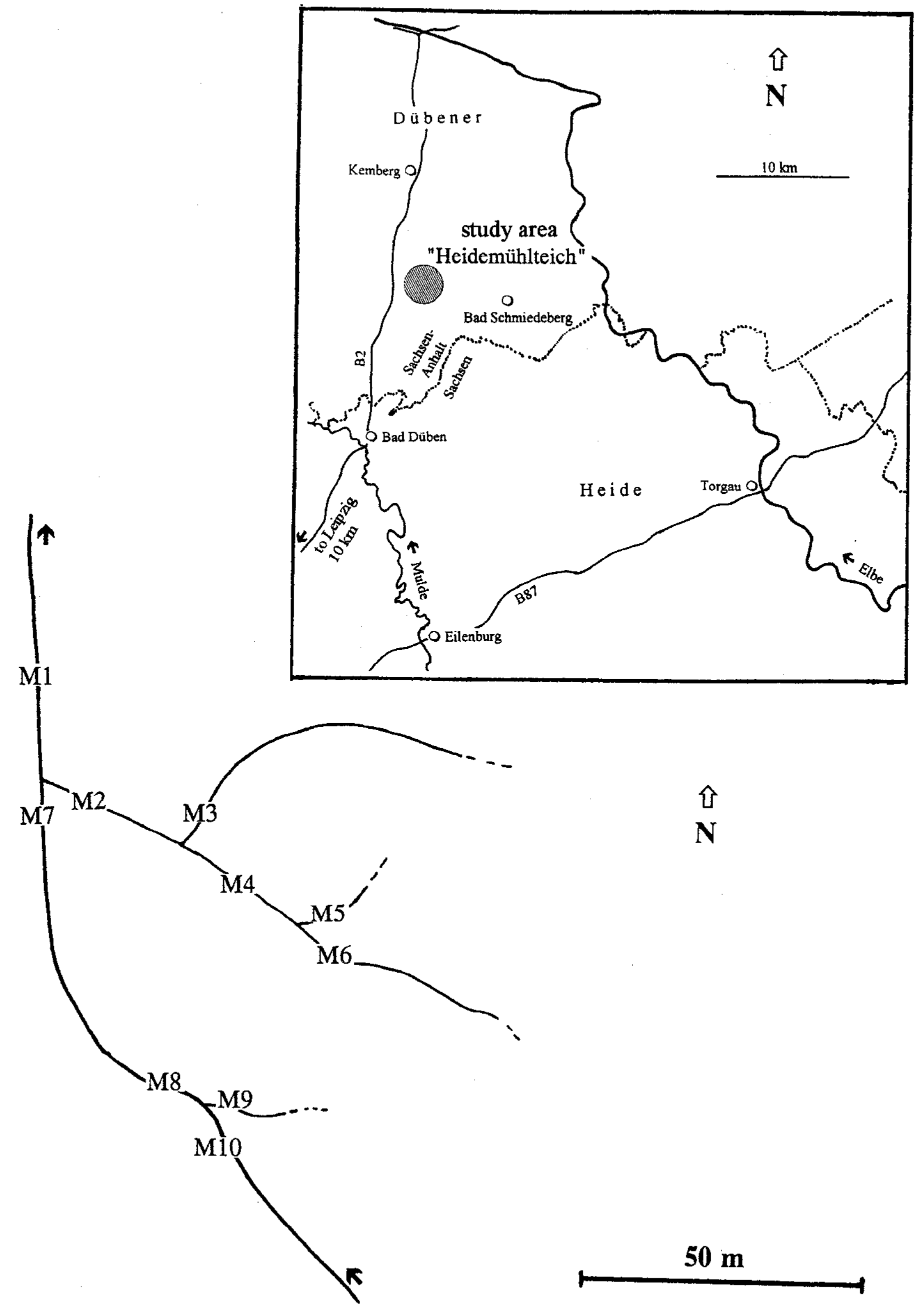

Fig. 1. Sample sites of the Heidenmühle brook system (dotted lines: borders of Saxonia, Saxonia-Anhalt, Brandenburg).

species between the main brook and the tributaries. Later pH-measurements showed surprising differences in the milieu within a small area, that could explain these distribution patterns. These fact gave the idea to study distribution patterns of representative sensitive species in this spring area.

The study presented supports the important ecological relevance of neutral spring regions for those brooks that could be recolonized after a possible restoration (e.g. by liming). Moreover it should show how a small scale mosaic of stream acidification in the investigated area can be concluded from the colonization patterns of the three mentioned sensitive taxa as representatives for the ceonoses of this habitat. Altogether it should be enhanced what extraordinary regenerative and ecological importance small biotopes like springs areas have in such a various shaped forest landscape, that is threatened by increasing acidification.

2. Description of the sample sites – Investigated Area

The investigations took place at an inflow to the Heidemühlteich in a forested part of the Dübener Heide (Sachsen-Anhalt; HW: 5729,575; RW: 4544,150 [TK 25, Blatt 4241 Kemberg, Normalausgabe, 1993]). The area is glacial-dominated (moraine), limited in the east by the southern part of the Torgau-Magdeburger Elbe-valley and in the west by the River Mulde. Within the investigation area the total fallout contained 42.0 kg SO_4–S per ha and a and 19.7 kg Ca, 1.66 kg Mg and 12.8 kg K between May 1993 and April 1994 [average; according to NIEHUS & BRÜGGEMANN (1995)]. Data from another sampling point at the Dübener Heide Heathland show that in the consequence of the industrial breakdown after the reunion of Germany the deposition of SO_4–S decreased to less than 30% of the value from the 1980ies to 1993/94, the other elements mentioned to even less (12%, 1% and 22% respectively). The highest emissions of SO_2 and dust took place in the 1970ies (NEUMEISTER et al. 1991). According to the composition of the emissions and the special deposition characters of their components, the authors documented a spatial gradient of the fallout from near to far to the emittent. The investigation area is situated in an intermediate position between the poles. An extensive hydrological and physical-chemical characterization of selected brooks in this impacted region is given by REINHART (1996).

The medium summer-warm main brook (M1, M7, M8, M10; Fig. 1) is a 2nd order stream according to STRAHLERS's definition (1952, 1957) with seasonal strongly variable discharge levels (see Fig. 2). It develops by the union of mainly two smaller spring brooks, of which REINHART (1996) showed the one to be strongly acidic (pH from 3.21 to 3.82) and the other at the most slightly (pH from 5.94 to 6.08). Moreover further input of strongly-acidic overflow water from a pond that is situated upstream the investigated area has to be expected at high floods. The investigated stream section is partly stretched and winded and trees and grass grow along its riparian areas. It is between 40 and 100 cm wide and between 10 and 40 cm deep. Partly, *Glyceria fluitans* grows strong. The substrate is dominated by coarse and fine detritus. During earlier

Table 1. pH and ANC (μeq/l) measured at the sample sites of the Heidemühle brook system (see Fig. 1); ANC = $(\Sigma Ca^{2+} + \Sigma Mg^{2+} + Na^+ + K^+) - (\Sigma SO_4^{2-} + NO_3^- - Cl^-)$; sample sites of the main brook *underlined and in italics.*
• not determined.

pH

Date	*M1*	M2	M3	M4	M5	M6	*M7*	*M8*	M9	*M10*
08/08/1995	*6.03*	6.02	6.38	6.17	5.70	6.01	*5.50*	*5.52*	6.64	*5.55*
21/09/1995	*6.17*	6.28	.	.	.	.	*5.59*	*5.68*	6.27	*5.70*
29/09/1995	*5.33*	6.02	.	.	.	.	*4.78*	*4.90*	5.98	*4.89*
05/10/1995	*5.71*	6.06	.	.	.	.	*5.01*	*5.02*	6.43	*5.00*
11/10/1995	*5.76*	6.02	6.02	6.00	5.91	5.98	*5.48*	*5.38*	6.40	*5.35*
27/02/1996	*5.27*	5.90	.	.	.	.	*5.25*	*5.85*	5.88	*4.56*

ANC (μeq/l)

Date	*M1*	M2	M3	M4	M5	M6	*M7*	*M8*	M9	*M10*
08/08/1995	*479.03*	549.29	513.86	504.92	582.74	566.32	*267.08*	*264.34*	418.97	*247.97*
11/10/1995	*234.53*	666.59	612.42	601.37	644.98	637.49	*139.04*	*112.42*	378.68	*106.37*
23/11/1995	*59.63*	628.60	.	.	.	.	*−95.30*	*−110.40*	427.86	*−237.93*

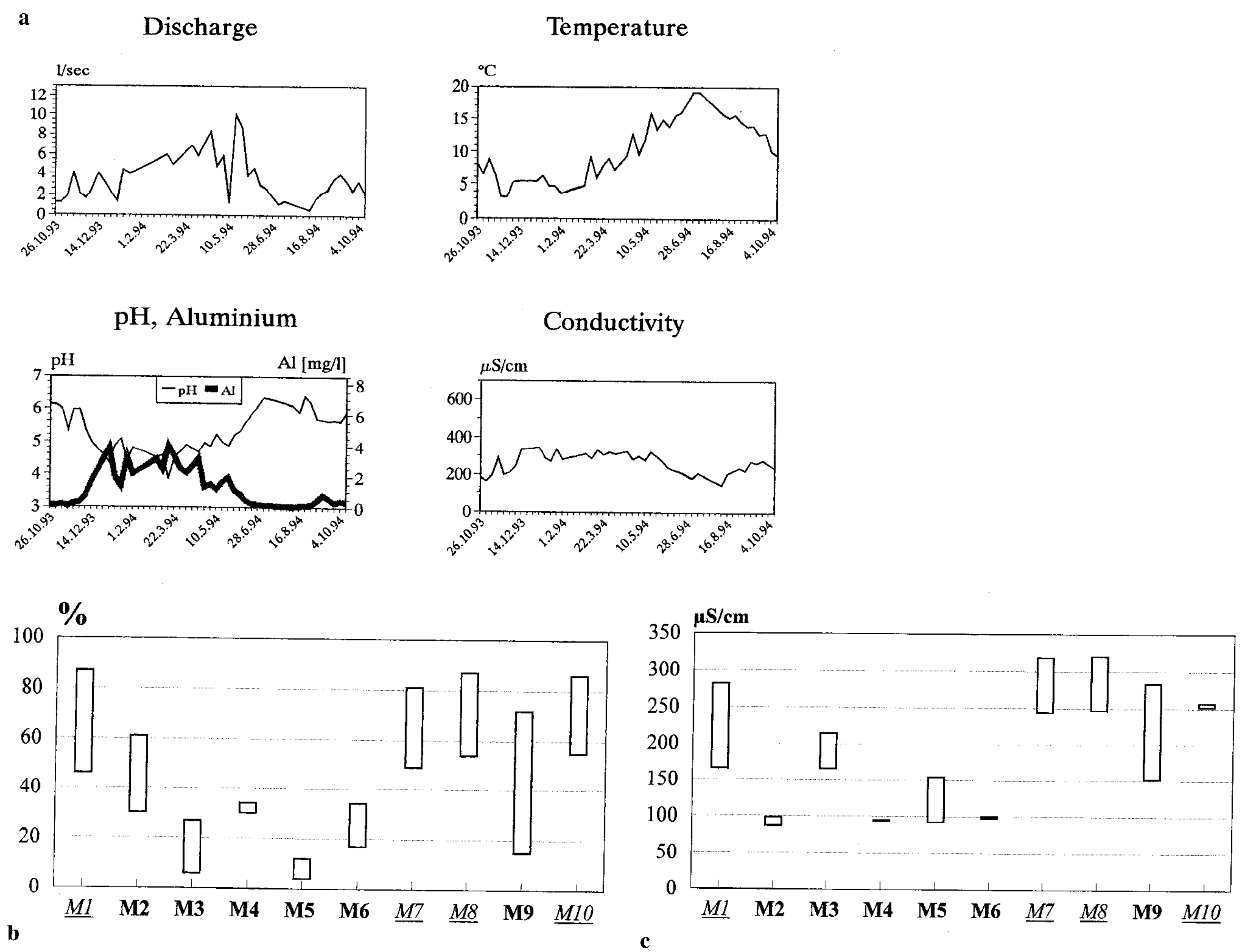

Fig. 2. a. Physical-chemical parameters at the main brook 1993/94 [M1, M7, M8, M10; according to ORENDT (1996)]. **b.** Oxygen (in % saturation) at the sample sites (maximum/minimum from Aug 8, 1995 to Feb 27, 1996); M1, M2, M7: n = 10; M3–M6: n = 2; M8–M10; n = 6); sample sites of the main brook underlined and in italics. **c.** Conductivity at the sample sites (maximum/minimum from Aug 8, 1995 to Feb 27, 1996); M1, M2, M7: n = 10; M3–M6: n = 2; M8–M10: n = 7).

investigations (1993/94; see ORENDT 1996) a decrease of the pH-level in winter and spring from neutral to strong acid levels could be recorded in the water, that correlated with higher discharges ($r_s = -0.795$; $p = 0.001$). In the upper reaches, some measurements showed a clearly lower acid neutralization capacity (ANC) than in the tributing small waters (Table 1), characterized by some negative values which indicate an episodical acidification. The aluminium concentrations was well increased to toxic levels (Fig. 2).

The tributaries (M2–M6, M9) are located under black alder, birches and scattered pines. The brooks have mainly organic mud-substrate, little up to very little discharge or a standing waterbody (M3), width of 20–30 cm, depth around 1–5 cm and a strong riparian grass growth. All investigated brooks were not inhabited by fish. These spring waters are characterized by lower ion concentrations and lower oxygen saturation, but by a clearly higher ANC than the main brook (M1, M7, M8, M10; Fig. 2b, c, Table 1).

3. Material and Methods

At the sample sites M1, M2, M7–10 pH-level, oxygen and temperature were measured on Aug 8, Sept 21, Sept 29, Oct 5, Oct 11, 1995 and Feb 27, 1996 (at the sample sites M3–M6 only on Aug 8 and Oct 11, 1995). Measurements of pH, oxygen, conductivity an temperature were performed in the field with the instruments pH 95, Oxi320 and Lf96B of WTW Ltd. *G. pulex* (Amphipoda), *A. aquaticus* (Isopoda) and *Pisidium* sp. (Mollusca) were sampled at the main brook (samples sites M1, M7, M8, M10; see Fig. 1) and at two tributaries (spring-brook system, sample sites M2–M6, M9) on Aug 8, 1995, Oct 11, 1995 and Feb 27, 1996 at the brook system in the Heidemühlteich pond.

For collecting in the soft sediments and coarse detritus a kitchen sieve (ca. 1500 µm mesh size) and a hand net (500 µm mesh size) were used. We estimated that about 0.3 m^2 surface of the sediment (the upper layer of about 5 cm) were taken for sieving. From the contents of the net samples macroinvertebrates were sorted out in a shallow tray. Furthermore, evertebrates were sampled from coarse detritus. The abundance was estimated in seven classes (according to MAUCH et al. 1990), as the structure of the habitats did not allow to take quantitative samples. Some specimens of each taxon were conserved in 75% ethanole for reference and for further determination, if they could not be identified exactly in the field. The sampling time for macroinvertebrates in the field was around 20 minutes for each sample site.

The assessment of the state of acidity was done according to BRAUKMANN (1992) with the threshold value of 3 for abundance of acid-sensitive taxa. The pH-levels were tested for significant differences with the U-Test (Mann-Whitney; $p < 0.05$).

4. Results

4.1. Main-brook-section (M1, M7, M8, M10) without tributary spring brooks

The acid-sensitive *G. pulex* and *Pisidium* sp. were found only singularly in the area of M1 and M7 at the several dates of investigation 1993/94 (ORENDT 1996). In 1995/96 *G. pulex* also showed no higher abundance and was totally absent further up the stream (M8, M10). *Pisidium* sp. appeared in the investigation 1995/96 regularly shortly after the inflow of M2, further up (M7, M8) in small amounts, but not all sample dates and never at M10. *Asellus aquaticus* was only found once in February 1996 after the inflow of M9 at M8.

The coenosis of the brook in 1993/1994 was moreover constantly represented by acid-tolerant taxa like *Nemurella picteti* (Plecoptera), *Plectrocnemia conspersa* (Trichoptera), *Heterotrissocladius marcidus* (Diptera, Chironomidae), and the acidophilic *Macropelopia adaucta* (Chironomidae). Furthermore the abundant appearance of *H. marcidus* in October 1993 indicates a mainly acidic milieu. This species appears to find good living conditions in acidic biotopes (ROMMELMANN & HEITKAMP 1989) or can at least tolerate them (ORENDT, unpubl.). The assessment of the stream acidity according to BRAUKMANN (1992) of the whole-year-coenoses resulted in state of acidity 2 ("episodically slightly acidic"; *whole-year-coenosis* = coenosis of all taxa found in the course of the investigated year). The weak populations of *G. pulex* and *Pisidium* sp. indicate a tendency towards a smaller acidity load. Communities of diatoms indicate a high degree of acidification (state of acidity 4; see HOFMANN 1994 and ORENDT 1996). Considering the pH-regime, the brook is ranked in state 3 ("periodically acidic") according to the BRAUKMANN classification. The latter, however is an optimistic assessment. It results from the assumption that 2 of 42 measured pH values can be considered as outliers. If they were not outliers, the evaluation would results in state 4 of acidity 4 ("permanently acidic").

4.2. Tributary area of the brook section (including spring brooks at sites M2–M6 and M9)

The measurements of physico-chemical parameters show significant differences in the relatively short period of investigation:

The pH-levels in the brooks of the side system were all on circumneutral level (Table 1). On the other side, all sample points in the main brook (M7, M8, M10) except the lowest point M2 had significant lower pH-levels (average between 5.0 and 5.5) than the tributaries (M3–M6; Fig. 3, Table 1); after the inflow of the last circumneutral tributary (M2) the pH-level of the main brook (at M1) did not differ significantly from that at the last inflow (M2).

The situation appears as this: The main brook carries acidic water in its upper part. The tributaries from the spring area (M2–M6, M9) add neutral water (Table 1), although apparently only the runoff of the last tributary (M2) is high enough to increase the pH-level of the main brook to a lower acidity level. The measurements of the ANC support this interpretation.

The distribution of the acid-sensitive taxa *G. pulex, A. aquaticus* and *Pisidium* sp. supports that the above mentioned acidity-pattern indicates a long term condition: Fig. 6 shows a recognizable abundance (class 4) of *Pisidium* sp. in the circumneutral tributaries (M2–M6, M9) and only small abundance (class 2) or absence in the acidic main brook (M1, M7, M8, M10) up to the neutralizing inflow of the lower tributary (M2), that apparently enables a stronger abundance of that taxon.

This effect is not as clear as for the crustaceans: *G. pulex* was only recorded in higher abundance in the

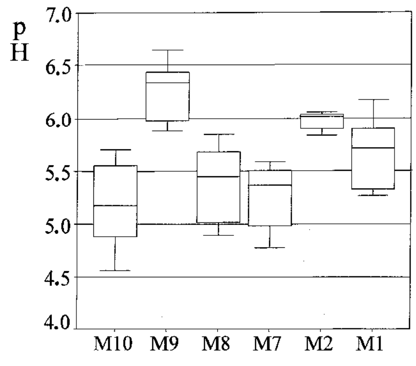

Fig. 3. pH-values of the Heidemühle brook system (without M3–M6, 50% of the values within a box, median and maximum/minimum, n = 6).

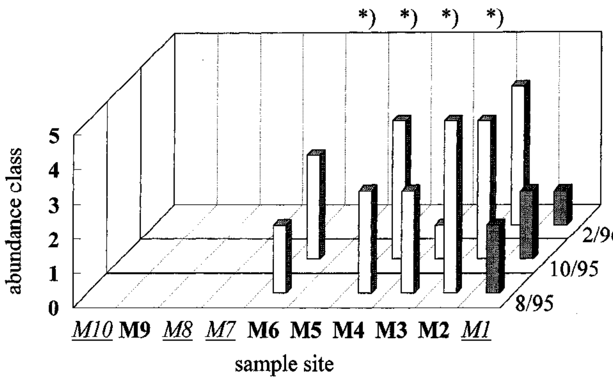

Fig. 4. *Gammarus pulex* at the sample sites of the Heidemühle brook system (see Fig. 1); abundance classes from 1 to 7; *) = no data from Feb 27, 1996; sample sites of the main brook: dark columns, labels underlined and in italics.

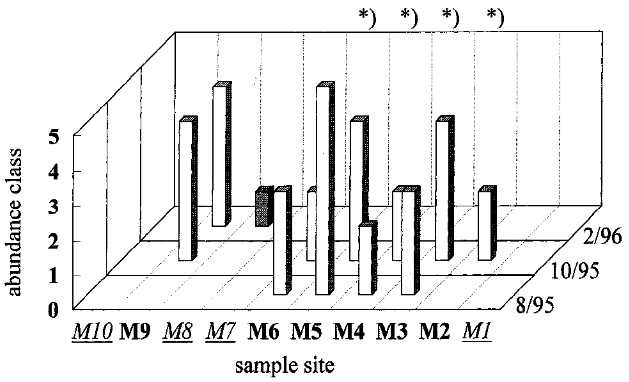

Fig. 5. *Asellus aquaticus* at the sample sites of the Heidemühle brook system (see Fig. 1); abundance classes from 1 to 7); *) = no data from Feb 27, 1996; sample sites of the main brook: dark columns, labels underlined and in italics.

lower tributary (M2) and in smaller abundance below the inflow (M1) (Figs. 4 and 5). The missing abundance in the upper inflow (M9) will be discussed later (section 5.1.). The habitat structures of the main brook would lead to expect a colonization by *A. aquaticus* in high abundance.

5. Discussion

5.1. Remarks on the investigated species

- *Gammarus pulex*

This species is classified as highly acid-sensitive by BRAUKMANN (1992). The sensitivity of the amphipods to acid is well documented [e.g. OKLAND & OKLAND (1980), cit. in MATTHIAS (1983)]. In studies of COSTA (1967) the species showed escaping behaviour from pH 6.2 on. MEIJERING (1984) reports acute damages of individuals of this and the sister species *G. fossarum* at pH 4.5–4.0. These pH-levels were only found in the upper stream section (M10) during the sample period. The single records in the main brook apparently indicate a threshold value for the existing of the species. Actually, *G. pulex* was found in the Dübener und Dahlerner Heide only in samples down to pH 4.7 (Table 2, Fig. 7). The water of the brook of this ecosystem fell short of this value several times in the 1993/94 investigation (see Fig. 2a ORENDT 1996). However, appropriate substrate for the species was present here.

The distribution of *G. pulex* in the investigated area can be closely linked to the state of the acidity of the brook. After the inflow of the tributaries only pH-levels between 5.3 and 6.2 (Fig. 3) were measured at M1. Therefore, it appears that only at high flood events the entire length of the brook reaches critical acid-levels and is not inhabitable for *G. pulex*. But in the neutral tributary (M2) considerable populations could be found.

The species apparently colonizes the main brook regularly from the tributary M2 and is extinct regularly by high acid loads so that the single record represented residue abundance of failed colonization attempts.

A possible explanation for the absence of *G. pulex* in the upper tributary M9 is that the isolated population is already extinct and the environmental factors (low water-depth etc.) do not allow a successful recolonization. It is also possible that at phases of high discharge acidic water inundates the small beds of M9 and provides a milieu that does not allow the survival of this amphipod, but well of *A. aquaticus* which is often considered as less sensible to acid than *G. pulex* (e.g. HARGEBY 1990). The author states that interspecific competition between the two species gives an advantage to *A. aquaticus* while acidic conditions can be excluded.

- *Asellus aquaticus*

This isopod is assessed differently in respect to its acid-sensitivity. For instance, ERIKSSON et al. (1983) call it very pH-tolerant, as opposed to JOHNSON et al. (1993), which mention it as an indicator for good buffered systems.

Following the list of bioindicators of the acidity-assessment according to Braukmann (1992), it only colonizes "non acidic streams" and at the most "critical acidic standing waters". This would indicate a very high acid-sensitivity. The species prefer places of low stream velocity with detritus and fine-muddy substrates, that were sufficiently apparent in the neutral spring tributaries and partly also in the main brook. In congruence with that, *A. aquaticus* was also found at those points where no high states of acidity dominated the brooks (M2–M6, M9), singularly also directly in the main brook shortly below the inflow of M9 (Fig. 5).

Table 2. Records and abundance [in classes from 1 to 7; see MAUCH et al. (1990)] of *Gammarus pulex* and *Pisidium* sp. at different levels of pH and concentrations of aluminium in samples at the Dübener und Dahlener Heide region [including data from 1993/94, see ORENDT (1996)].
– not recorded; • not determined.

Gammarus pulex	Pisidium sp.	pH	Al [mg/l]	Sample site	Date
–	3	6.80	.	Heidemühle M9	11/10/95
–	2	6.64	.	Heidemühle M9	08/08/95
5	3	6.62	0.183	Ochsenkopf	26/10/93
6	2	6.54	0.080	Ochsenkopf	29/03/94
4	–	6.48	0.130	Parnitz	29/03/94
4	2	6.44	0.250	Parnitz	26/10/93
4	2	6.38	0.180	Parnitz	31/05/94
2	–	6.35	0.250	Parnitz	13/09/94
–	–	6.27	0.094	Ausreißer	26/10/93
4	2	6.25	0.058	Ochsenkopf	31/05/94
–	–	6.12	0.085	Heidemühle M1	26/10/93
–	–	6.03	.	Heidemühle M1	08/08/95
4	2	6.02	.	Heidemühle M2	11710/95
2	3	6.02	.	Heidemühle M2	08/08/95
4	2	5.92	0.053	Ochsenkopf	13/09/94
4	2	5.90	.	Heidemühle M2	27/02/96
–	3	5.88	.	Heidemühle M9	27/02/96
2	2	5.76	.	Heidemühle M1	11/10/95
1	1	5.67	0.771	Heidemühle M1	13/09/94
–	–	5.55	.	Heidemühle M10	08/08/95
–	–	5.52	.	Heidemühle M8	08/08/95
–	1	5.50	.	Heidemühle M7	08/08/95
–	1	5.48	.	Heidemühle M7	11/10/95
–	2	5.38	.	Heidemühle M8	11/10/95
–	–	5.35	.	Heidemühle M10	11/10/95
1	2	5.27	.	Heidemühle M1	27/02/96
–	–	5.25	1.180	Ausreißer	13/09/94
–	–	5.25	.	Heidemühle M7	27/02/96
–	1	5.22	1.070	Heidemühle M1	31/05/94
–	2	4.85	.	Heidemühle M8	27/02/96
–	–	4.83	1.660	Ausreißer	31/05/94
1	1	4.70	2.510	Heidemühle M1	29/03/94
–	–	4.56	.	Heidemühle M10	27/02/96
–	–	4.49	5.260	Ausreißer	29/03/94
–	–	3.95	4.680	Lausa	29/03/94
–	–	3.93	2.650	Taura	31/05/94
–	–	3.92	5.030	Taura	29/03/94
–	–	3.83	5.210	Taura	26/10/93
–	–	3.80	3.080	Lausa	31/05/94
–	–	3.72	6.260	Taura	13/09/94

The individuals only appeared on the brookside of the mouth and disappear very fast in the further course although substrates for a colonization are at hand. *Pisidium* sp. (see below) showed the same colonization pattern.

Like *G. pulex*, the individuals of this species regularly colonized the stream of the next higher order but were unable to establish a stable and lasting population, apparently because of the surrounding milieu.

• *Pisidium* sp.

In the investigated area one species of these mussels has been identified (*P. casertanum*, see ORENDT 1996). *P. casertanum* appears as eurytopic, euryoecius and extremely tolerant, even towards varying pH-levels (GLOER & MEIER-BROOK 1994). In the lime-poor Scandinavian lakes the density of the individuals of the taxon *Pisidium* decreased clearly from a pH 6.0 on although single individuals were found up to a pH 4.2 (NILLSEN 1980). BRAUKMANN (1992) indicates the second highest acid-sensitivity-level for the taxon *Pisidum* spp. These mussels are sometimes considered problematic for the detection of acidification (Dr. G. SCHNELBÖGL, Bayer. Landesamt f. Wasserwirtschaft, pers. communication), because they possibly protect themselves temporarily from strong acid loads by digging themselves into the sediment (comp. MATTHIAS 1983: 426) and tightly closing their shells. This ability is of only little use in permanent acidic waters, though. Consequently, no *Pisidium*-species were found in those waters (ORENDT, in prep.). The taxon has to be classified as moderately acid-sensitive. Like *G. pulex, Pisidium* sp. could regularly be found in samples with a minimum pH of 4.7 in the Dübener and Dahlener Heide (Fig. 7 and Table 2).

In the presented study, this taxon is the widest and most regularly distributed of the three discussed taxa (Fig. 6). Like *A. aquaticus* the last individuals soon disappear after the inflow of M9 in the further course of the brook. Opposite to that, single individuals could be found in the main brook below M2 together with single *G. pulex*. At this site, the inflow of neutral water from M2 apparently enables a scattered residue abundance of these relatively immobile molluscs.

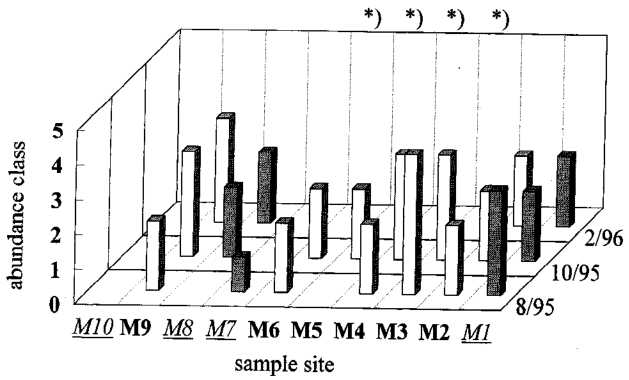

Fig. 6. *Pisidium* sp. at the sample sites of the Heidemühle brook system (see Fig. 1); abundance classes from 1 to 7, *) = no data from Feb 27, 1996; sample sites of the main brook: dark columns, labels underlined and in italics.

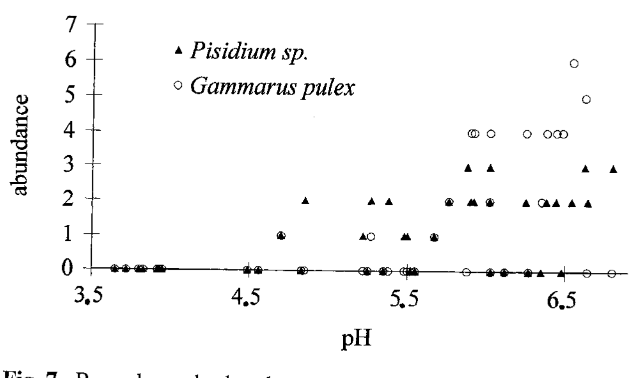

Fig. 7. Records and abundance [in classes from 1 to 7; see MAUCH et al. (1990)] of *Gammarus pulex* and *Pisidium* sp. at different levels of pH.

5.2. Problems in assessing the state of acidity

The answer to the question, if macoinvertebrates can regularly colonize or actually survive in the main brook struck by acid (M1, M7, M8, M10) is essential for the practical assessment. According to the investigation of the tributaries it appears that the tributaries (M2–M6, M9) hold the main abundance of sensitive species and not the main brook (M1, M7, M8, M10). It seems to be obvious that these forms regularly colonize the main brook from the acid-protected tributaries, but do not exist as an autochthone population there. If the sensitive organisms flooded in from the tributaries are taken as an indicator, not the real state of acidity would be rated, but only an artefact. This is clarified by the following example:

The assessment of the main brook [according to the method of BRAUKMANN (1992)] corresponding to investigations 1993/94 was very heterogeneous (ORENDT 1996):

- pH measurements [according to the BRAUKMANN classification (1992)]: state of acidity 3, "periodically acidic" (resp. 4, "permanently acidic", see section 4.1.)
- diatoms: state of acidity 4 ("permanently acidic")
- macroinvertebrates: summarized species-list of the investigation-period 1993/94 (*whole year-coenosis*): state of acidity 2 ("episodically acidic"); *seasonal coenoses*: three times (4. 10. 93, 1. 6. 94, 16. 9. 94) state of acidity 4 ("permanently acidic"), once (28. 3. 94) state of acidity 2 ("episodically slightly acidic").

Thus, at this location three different of four possible acidity-states were indicated. By the parallel measuring of the pH-levels we were able to decide that the evaluation of the whole-year-coenosis with a abundance-threshold value of 3 for the acid-sensitive macroinvertebrates did not lead to reasonable results at those investigations (Fig. 8). A more correct picture can be drawn from the evaluation of the sesonal coenoses (in correspondence with the evaluation of the diatoms). On the other hand, the regular presence of acid-sensitive species (*G. pulex, Pisidium* sp.), which appeared considerable only in the evaluation of the whole-year-coenosis, can not be ignored.

The results of this study show that sensitive forms (*A. aquaticus, G. pulex, Pisidium* sp.) found in the main brook (M1, M7, M8, M10) immigrate or are flooded in, but are not representatives of the coenosis there. Consequently, they have to be excluded from the evaluation of that brook section. A main result is that the new assessment of this sample location (without those taxa) by the whole-year-coenosis indicated the state of acidity 4 ("permanently acidic") (in correspondence with the indi-

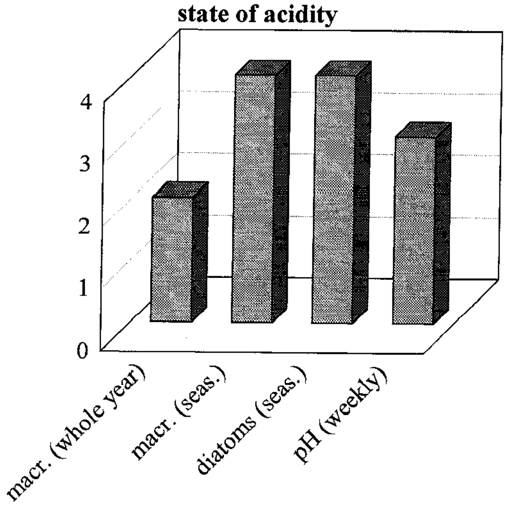

Fig. 8. Assessment of the state of acidity at the main brook 1993/94 [M1, M7, M8, M10; see ORENDT (1996) by macroinvertebrates (whole-year-coenoses, seasonal coenoses) according to BRAUKMANN (1992), epilithic diatoms (seasonal coenoses) according to HOFMANN (1994) and weekly pH measurements.

cation by the seasonal coenosis as well as by the diatoms; see ORENDT, in prep.). The total evaluation of the coenoses of the single sample dates (once state 2 and three times state 4, that follows according to the practice in water-surveillance also to a total state of 4) would result in this case in the same evaluation as by the diatoms ("permanently acidic") and the pH-regime (if the criteria for evaluation were applied rigorously, see above).

In the investigations of the Heidmühle brook system and its catchment area it became clear that the state of acidity of the main brook evaluated firstly does not correspond with the tributaries of the surrounding area. The streams of the whole area are not all acidified. The investigated section of the main brook (M10, M8, M7, M1) is fed with acidified water from further above but also receives neutral water (M2–M6, M9). But this (and possibly by geochemical reations with the bottom of the brook too), the acidity-concentration is lowered significantly.

The results of this study suggest that the spring tributaries function as a reproduction and refuge area for populations of sensitive species, that are otherwise isolated from each other by the acidified main brook. From there these organisms continually try to recolonize the stream. However, an exact detection of the recolonization process is only possible by studying the population dynamics of the species mentioned. Another explanation for the distribution pattern found in this running water system would be that here we observed the last specimens of disappearing populations of the focussed species in the main brook. However, this is probably not the case, as we can assume – indicated by the measurements of pH regime and ANC of the main brook – that the highly acidic periods return regularly for a considerable time, in any case longer time than some generations of the pH-sensitive forms last.

For the assessment of the state of acidity by macroinvertebrates with procedures used in the water-surveillance knowledge about the situation of the acidity of the catchment area has to be included, so that assessments will not lead to wrong results. This would have also impacts on a correct large scale assessment of the region.

6. Final remarks – Outlook

Extinguished acid-sensitive organisms are able to recolonize acidified waters after restoration of the milieu. According to studies of ERIKSSON et al. (1983) some benthic taxa (molluscs and crustaceans) had yet difficulties with recolonization. The requirement for an effective recolonization of the investigated acidified water is that populations for colonization exist in the tributaries, as could be described by experiments by GRIFFITHS (1992). In the investigated stream system Heidemühle, acid-sensitive forms can be considered to hold such a refuge area. Therefore, these spring areas have highest priority for protection, because the regeneration of certain landscape-typical elements (like forest brooks) begins there. Once again it becomes clear that the spring regions need more detailed research and should not be neglected, as so far. From the observations in this study, we can conclude that the Dübener Heide is a mosaic of streams on a small scale with different states of acidity. The assessment of the states by macroinvertebrates could lead to locally wrong assessments, if the observed recultivation and inflowing effects from the refuge areas were not adequately taken into account. Therefore it is recommended to establish a random survey of the colonization patterns of the acid-sensitive taxa in the catchment area before an actual assessment of selected waters.

Acknowledgements

We wish to thank to Dr. F. FOECKLER and S. MEHLERT for the critical discussion of the results and the revision of language.

References

BAUER, J., SCHMITT, P., LEHMANN, R. & FISCHER-SCHERL, TH. (1987): Untersuchungen zur Gewässerversauerung im Modellgebiet Obere Waldnaab (Oberpfälzer Wald, Nord-Ostbayern). Ber. Akad. f. Naturschutz u. Landschaftspflege (ANL) **11**: 139–170 (Laufen).

BRAUCKMANN, U. (1992): Biological indication of stream acidity in Baden-Württemberg. In: BÖHMER, J. & RAHMANN, H. (eds.): Bioindikationsverfahren zur Gewässerversauerung. Landesanstalt. Umweltschutz Baden-Württemberg, Veröffentlichungen Projekt „Angewandte Ökologie" Bd. **3**: 58–71 (Karlsruhe).

COSTA, H. H. (1967): Responses of *Gammarus pulex* (L.) to modified environment. II. Reactions to abnormal hydrogen ions. Crustaceana **13**: 1–10.

ERIKSSON, F., HÖRNSTRÖM, E., MOSSBERG, P. & NYBERG, P. (1983): Ecological effects of lime treatment of acidifield lakes and rivers in Sweden. Hydrobiologia **101**: 145–164.

GLOER, P. & MEIER-BROOK, C. (1994): Süßwassermollusken. Ein Bestimmungsschlüssel für die Bundesrepublik Deutschland. 11. Aufl. Deutscher Jugendbund für Naturbeobachtung, Hamburg, 136 pp.

GRIFFITHS, R. W. (1992): Effects of pH on community dynamics of Chironomidae in a large river near Sudbury, Ontario. Can. J. Fish. Aquat. Sci. **49**, Suppl. **1**: 76–86.

HEITKAMP, U. & LESSMANN, D. (eds.) (1990): Fallstudie Harz: Auswirkungen der Gewässerversauerung auf Bergbach- und Seebiozönosen. Ergebnisse der Untersuchungen 1986–1989. Ber. d. Forschungszentr. Waldökosysteme Reihe B, Bd. **19**: 1–294 (Göttingen).

HARGEBY, A. (1990): Effects of pH, humic substances and animal interactions on survival and physiological status. A field experiment. Oecologia **82**: 348–354.

HOFMANN, G. (1987): Diatomengesellschaften saurer Gewässer des Odenwaldes und ihre Veränderungen durch anthropogene Faktoren. Master Thesis, University of Frankfurt/M., Dept. of Biology.

– (1994): Untersuchung zu Diatomengesellschaften des Aufwuchses in ausgewählten Gewässern der Dübener und Dahlener Heide. Centre für Environmental Research Leipzig–Halle GmbH, Project Area of Natural Landscapes, Report (not publ.), 16 pp. + Appendix.

JOHNSON, R. K., WIEDERHOLM, T. & ROSENBERG, D. M. (1993): Freshwater biomonitoring using individual organisms, populations, and species assemblages of benthic macroinvertebrates. In: ROSENBERG, D. M. & RESH, V. H. (eds.): Freshwater biomonitoring and benthic macroinvertebrates. Chapman and Hall, New York, London, pp. 40–158.

LEUVEN, R. S. E., VAN DER VELDEN, J. A., VANHEMELRIJK, J. A. M. & VAN DER VELDEN, G. (1987): Impact of acidification on chironomid communities in poorly buffered waters in the Netherlands. Ent. Scand., Suppl. **29**: 269–280.

MATTHIAS, U. (1983): Der Einfluß der Versauerung auf die Zusammensetzung von Bergbachbiozönosen, Arch. Hydrobiol., Suppl. **65**: 407–483.

MATSCHULLAT, J., HEINRICHS, H., SCHNEIDER, J., & ULRICH, B. (eds.) (1994): Ökosysteme und Wasserqualität. Ergebnisse interdisziplinärer Forschung im Harz. Springer, Berlin, Heidelberg, 478 pp.

MAUCH, E., SANZIN, W. & KOHMANN, F. (1990): Biologische Gewässeranalyse in Bayern – Taxaliste der Gewässerorganismen. Inf. Ber. Bayer. Landesamt Wasserwirtschaft **4/90** (München).

MEIJERING, M. P. D. (1984): Auswirkungen saurer Niederschläge auf Bäche. Wissenschaft und Umwelt **2/1984**: 102–104.

NEUMEISTER, H., FRANKE, CH., NAGEL, CH., PEKLO, G., ZIERATH, R. & PEKLO, P. (1991): Immissionsbedingte Stoffeinträge aus der Luft als geomorphologischer Faktor. 100 Jahre atmosphärische Deposition im Raum Bitterfeld (Sachsen-Anhalt). Geoökodynamik (Bensheim) **12**: 1–40.

NIEHUS, B. & BRÜGGEMANN, L. (1995): Untersuchungen zur Deposition luftgetragener Stoffe in der Dübener Heide. Beitr. Forstwirtsch. Landschaftsökol. **29** (4): 160–163.

NILLSEN, J. P. (1980): Acidification of a small watershed in Southern Norway and some characteristics of acidic environments. Int. Rev. ges. Hydrobiol. **65**: 177–207.

ORENDT, C. (1996): Bioindikation in Kleinfließgewässern der Dübener und Dahlener Heide. UFZ-Berichte Nr. 2/1996 (Reports), Centre for Environmental Research Leipzig–Halle, 90 pp. + Appendix.

– (in prep.): Bioindication of acidification in forest spring brooks by macroinvertebrates and diatoms in a highly impacted region of eastern Germany (Leipzig–Halle–Bitterfeld).

– & WEISSFLOG, L. (1994): Einfluß des hydrochemischen Milieus auf Biozönosen in Kleinfließgewässern der Dübener und Dahlener Heide. In: GUHR, H., PRANGE, A., PUNCOCHAR, P., WILKEN, R.-D. & BÜTTNER, B. (eds.): Die Elbe im Spannungsfeld zwischen Ökologie und Ökonomie. B. G. Teubner Verlagsgesellschaft Stuttgart, Leipzig, pp. 485–488.

REINHART, U. (1996): Untersuchung der Mobilisierung sedimentierter Schwermetalle durch die Reduktion der kalkhaltigen Staubemission in der Dübener Heide. UFZ – Centre for Environmental Research, Leipzig–Halle, Final Report of the REGNAL Project, 19 pp. + Appendix (Leipzig).

ROMMELMANN, J. & HEITKAMP, U. (1989): Auswirkungen der Gewässerversauerung auf die Chironomidenbesiedlung (Diptera: Chironomidae) in Quellbächen der Senne, Ostwestfalen. Göttinger Naturk. Schr. **1**: 131–143.

STRAHLER, A. N. (1952): Hypsometric (area-altitude) analysis of erosional topography. Geol. Soc. Am. Bull. **63** (11): 1117–1142.

– (1957): Quantitative analysis of watershed geomorphology. Amer. Geophys. Union Trans. **38**: 913–92.

WEATHERLY, N. S. & THOMAS, S. P. (1989): Chemical and biological effects of acid aluminium and lime additions to a Welsh hill-stream. Environ. Poll. **56**: 283–297.

ZIERATH, R. (1981): Inhaltsstoffe atmosphärischer Niederschläge und ihr Einfluß auf die Sicker- und Grundwasserbeschaffenheit ausgewählter Gebiete. Ph.D. Thesis, Technical University Dresden, 115 pp.

Received: 02. 09. 1996

Address of the authors: Dr. CLAUS ORENDT, Hildegardstr. 13, D-80539 München; present address: Technical University of Brandenburg/Cottbus, Chair of Water Protection, Research Station Bad Saarow, Seestr. 45, D-15525 Bad Saarow, Germany; Dipl.-Geogr. UDO REINHART, Hochschule für Technik, Wirtschaft und Kultur, Karl-Liebknecht-Str. 132, D-04277 Leipzig, Germany.