*Journal of Insect Conservation* **4**: 79–91, 2000.


# The chironomid communities of woodland springs and spring brooks, severely endangered and impacted ecosystems in a lowland region of eastern Germany (Diptera: Chironomidae)

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Received 1 August 1998; accepted 2 February 2000

*Key words:* chironomids, crenophilic, cold-stenothermic, reference ecosystems, woodland

## Abstract

The distribution of chironomid species from four springs and twelve spring brooks in a region heavily affected by industrial activity in eastern Germany was studied. The aims were (1) to document the chironomid taxa communities at the species level, as far as possible, and the most important environmental factors of representative springs and spring brooks of the region, (2) to analyse the distribution of the ecological groups within these small ecosystems and (3) to emphasize the importance of the protection of spring areas and spring brooks in this woodland area shown by the chironomid fauna. There was high degree of abiotic variation among the water bodies, with pH ranging from 2.79 to 6.89. While diversity did not correlate with pH nor with conductivity, significant differences existed between the spring mouth and the reaches some metres downstream with respect to several abiotic parameters and the distribution of the chironomids: oxygen concentrations and taxonomic diversities were higher in spring brooks (2.18–8.98 mg $O_2$/l; 5–28 taxa) than in the spring areas (0.13–2.95 mg $O_2$/l; 0–7 taxa). A total of 74 chironomid taxa were recorded. The chironomid communities are characterized by the presence of rheophilic, cold-stenothermic, crenophilic and sometimes tyrphophilic elements in each site. The data show that each of the spring–spring brook systems surveyed is unique both in biotic and abiotic respects. As the spring system is sensitive to changes in landscape functions (e.g. groundwater levels), the fauna can serve as an indicator of landscape health. Therefore, these small ecosystems should be conserved as a reference.

## Introduction

Springs and spring brooks are often relatively small, overlooked ecosystems, and neglected in terms of their significance for landscape ecology and conservation in central Europe. As a consequence, these complex and vulnerable habitats and their particular communities are just as endangered as other components of the natural environment like floodplains or marshes, which frequently are larger and better known to the public. In the northeastern lowlands of Germany, Riecken *et al.* (1994) state that the rheocrene habitats are threatened by complete devastation, while the helocrenes are rated as 'strongly endangered'. Many invertebrate species found in such springs are strictly bound to the unique factors of these habitats (of which the Chironomidae represent a high proportion). Loss or destruction of such habitats would result in the elimination of highly adapted species. In recent years, several campaigns have commenced in Germany to protect the last refuges of the endangered spring fauna (Naturschutzzentrum NRW 1993), but knowledge about the ecology of spring species (food web and factors, distribution patterns and communities) is still meagre. Williams and Danks (1991) stated that in Canada the biological characteristics of spring systems are also relatively unknown, compared with most other aquatic habitats, and further information is required for most species. An overview of the most important needs for research is presented by Danks and Williams (1991).

The dipteran family Chironomidae is the taxonomic group with the highest abundances in the spring/spring brook complex. Nevertheless, chironomids are often neglected in spring investigations, even when the focus is on Diptera (e.g. Fischer *et al.* 1995, Thomes 1993). Lindegaard (1995) gave a comprehensive review of the chironomid literature on springs and discussed the main factors responsible for occurrence and distribution of Chironomidae in springs. However, compared to work in other freshwater ecosystems, surveys and comprehensive studies on habitats for Chironomidae in springs have been few (Thienemann 1954; Lindegaard, l.c.; Zavrel & Pax 1951; Crema *et al.* 1996). On the rare occasions that sampling and evaluation has occurred, identification was often only to the generic level (e.g. Colbo 1991). Occasionally, species were separated, but not identified (e.g. *Tanytarsus* A, B, C, . . . ; see Hayford *et al.* 1995). Studies comparing the chironomids at the *species level* for different springs and spring brooks are not common. Most studies considered only single sites, and many of these works are unpublished (e.g. as Master thesis Wagensonner 1992; Goldschmidt 1994; Schirmer 1990; Wenzl 1988) or not yet published. This study used mainly pupal exuviae, a developmental stage that allows determination at the species level, to compare the communities of different spring-influenced habitats. The aims of this paper are (1) to document the chironomid communities and the most important environmental factors in order to characterize representative springs and spring brooks of the region, (2) to analyse the distribution of the ecological groups within these small ecosystems, (3) to elaborate the importance of conserving spring areas and spring brooks in this woodland area as revealed by characteristic chironomids. The original data for six spring brooks and four springs are presented. To complete this overview of groundwater-influenced habitats in the forests, data from another study on spring brooks (Orendt 1998) are included in the evaluation.

## Investigated area – sample sites

The brooks in which the chironomids were collected, are located in the 'Dübener and Dahlener Heide Heathland', situated around 30 km to the north-east and east of Leipzig (Saxonia, Germany, see Figure 1). The area is characterized by glacial moraines covered with nutrient poor and dry loess and sand, in which scattered wet areas of moor are found. Much of the area is used for agricultural activities. The present forest vegetation is dominated by *Pinus* spp., though small remnant areas of heathland are found throughout. It is limited in the east by the southern part of the Torgau-Magdeburger Elbe valley and in the west by the Vereinigte Mulde river.

The region has been heavily affected by industrial activity in the recent past. Within the investigation area, the total fallout per ha and year contained an average of 42.0 kg $SO_4$–S, 19.7 kg Ca, 1.66 kg Mg and 12.8 kg K between May 1993 and April 1994 (Niehus & Brüggemann 1995). The highest emissions of $SO_2$ and dust took place in the 1970s (Neumeister *et al.* 1991), when 1000 tons $SO_2$ were estimated to be emitted each day, mainly from the chimneys of brown coal-fired power plants. Data from another sampling point at the Dübener Heide Heathland show that as a consequence of the regional industrial breakdown during the beginning of the 1990s, the deposition of $SO_4$–S decreased to less than 30% of the values from the 1980s to 1993/94. The other elements decreased to even less (Ca 12%, Mg 1% and K 22%; according data of Niehus & Brüggemann 1995). Taking account of the composition of the emissions and the special deposition characteristics of their components, the authors documented a spatial gradient for the fallout over some distance from the emitters towards the east. The emitters were situated near Leipzig in the south-western part of the region and in Bitterfeld in the north-west of the region. The investigation area is situated about half-way between the emitters and the end of the gradient. However, an extensive hydrological and physical–chemical characterization of several brooks (Ochsenkopf 1, Parnitz, Heidemühle, Ausreisser, Taura and Lausa) indicates that the impact of the gradient on surface water was considerably complicated by the presence of springs/brooks fed by groundwater (Reinhart & Orendt 1997). Nevertheless, in most water bodies which were dominated by interflow, acidic conditions were observed at least periodically, corresponding strongly to a high degree of acidification of the soil in the forest. Reinhart and Orendt (1997) recorded a gradient from non-acidified water bodies (Ochsenkopf 1, Parnitz) in the north-west (close to industrial emitters) to acidified water bodies (Taura, Lausa) in the south-east (far from industrial emitters). Further studies, however, showed that acidified and non-acidified water bodies are situated close to each other suggesting a pedological mosaic at a small scale. The effects of the acid on species

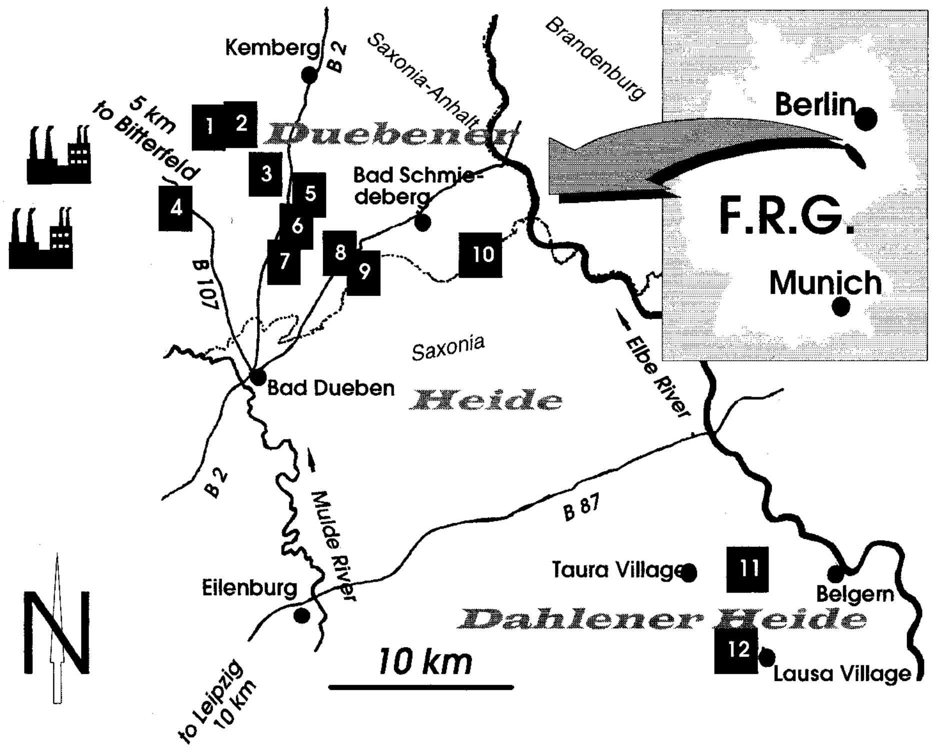


*Figure 1.* The investigation area and the position of the springs and spring brooks and the power plants Zschornewitz (above) and Muldenstein (below). 1 = Ochsenkopf 1, 2 = Ochsenkopf 2, 3 = Parnitz, 4 = Breitewitzer Bach, 5 = Heidemühle, 6 = Mark Schmelz, 7 = Lutherstein, 8 = Deubitzwiesen, 9 = Grenzbach, 10 = Ausreisser, 11 = Taura, 12 = Lausa.

distribution and communities in this water system was obvious (Orendt & Reinhart 1998): the acid-sensitive crustacean *Gammarus pulex* and the mussels *Pisidium* spp. were recorded only in refuges with neutral pH values and were lacking in low pH.

All water bodies investigated (Figure 1) are situated in forested land which is dominated by pines, with birches and black alders in moist areas. The beds of the stretches of the brooks investigated comprised mainly sandy and stony sediments with enrichments of organic and sometimes iron mud in lentic zones. Plant growth was extensive in some water bodies, such as *Glyceria fluitans* at Heidemühle and Lausa, and *Juncus* spp. and grasses in the brooks at Grenzbach and Deubitzwiesen. Discharge was estimated by drift method to be around 1.5–3.5 l/s, with extremes of > 4 l/s (Breitewitzer Bach) and < 1 l/s (Grenzbach, Deubitzwiesen). The stream sections are in part straight, in part winding; trees and grass grow along their riparian areas. The sections are between 40 and 100 cm wide and between 10 and 40 cm deep (at Breitewitzer Bach, Heidemühle). As the water bodies are small, none of the investigated brooks can support fish. The springs of Ochsenkopf 2, Lutherstein and Mark Schmelz are rheo-helocrenes, the spring of Breitewitzer Bach is a rheocrene. The latter, however, had dried out at the last sampling date. The spring region of Grenzbach and Deubitzwiesen resembles a ditch apparently fed by groundwater and interflow. This reflects complex discharge processes, also indicated by temperature (see Table 1; in accordance with van der Kamp 1995). An overview of the most important features of the water bodies is given in Table 2.

## Methods

Samples and measurements were taken at Lutherstein, Ochsenkopf 2, Mark Schmelz, Breitewitzer Bach, Grenzbach and Deubitzwiesen on 14 April, 6 May, 4 July, 30 August and 5 November 1996, in both the springs and the spring brooks. However, at the latter two sites, splitting of the sampling site into spring and spring brook was not possible, so samples were taken only in the ditches, which were considered here as ‘brooks’. The abiotic parameters were measured in

*Table 1.* Detailed overview of oxygen concentrations, temperature, conductivity and pH of the springs and spring brooks investigated in 1996.

| Site no.** | | Date | Oxygen (mg/l) | | Temperature (°C) | | Conductivity (μS/cm) | | pH | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Spring | Spring brook | Spring | Spring brook | Spring | Spring brook | Spring | Spring brook |
| 7 | Lutherstein | 17.04.96 | 2.95 | 7.20 | 14.5 | 12.2 | 30 | 68 | 4.55 | 5.87 |
| | | 06.05.96 | 2.17 | 7.04 | 7.8 | 10.3 | 19 | 64 | 5.32 | 5.94 |
| | | 04.07.96 | 1.67 | 7.88 | 15.5 | 11.7 | 151 | 81 | 5.40 | 5.45 |
| | | 30.08.96 | 1.92 | 5.60 | 11.3 | 11.3 | 152 | 83 | 5.10 | 5.45 |
| | | 05.11.96 | 1.45 | 4.59 | 10.1 | 10.8 | 155 | 87 | 4.73 | 5.46 |
| 4 | Breitewitzer Bach | 17.04.96 | 0.76 | 2.18 | 9.6 | 9.8 | · | · | 6.74 | · |
| | | 06.05.96 | 1.25 | 4.65 | 10.5 | 10.4 | 226 | 225 | 6.71 | 6.77 |
| | | 04.07.96 | 0.52 | 2.63 | 10.8 | 11.0 | · | · | · | 6.58 |
| | | 30.08.96 | 0.37 | 2.24 | 10.9 | 11.0 | 260 | 261 | 6.11 | 6.24 |
| | | 05.11.96 | Dried out | | Dried out | | Dried out | | Dried out | |
| 2 | Ochsenkopf 2 | 17.04.96 | · | · | 10.5 | 14.2 | · | · | 5.69 | 6.52 |
| | | 06.05.96 | 2.17 | 7.04 | · | · | · | · | · | 5.76 |
| | | 04.07.96 | 0.13 | 4.65 | 9.3 | 10.2 | · | 267 | · | 5.64 |
| | | 30.08.96 | 2.44 | 8.98 | 9.8 | 10.6 | 294 | 268 | 5.66 | 6.23 |
| | | 05.11.96 | 1.26 | 5.65 | 9.7 | 9.7 | 268 | 326 | 6.1 | 5.66 |
| 6 | Mark Schmelz | 17.04.96 | · | · | 9.2 | 9.9 | · | · | 5.62 | 5.96 |
| | | 06.05.96 | 0.45 | 7.55 | 10.5 | 11.0 | 169 | 168 | 5.74 | 6.35 |
| | | 04.07.96 | 0.49 | · | · | 11.0 | · | · | 5.67 | · |
| | | 30.08.96 | 0.36 | 4.7 | 11.5 | 11.2 | 161 | 179 | 5.97 | 5.69 |
| | | 05.11.96 | 0.47 | 4.63 | 10.8 | 10.9 | 173 | 174 | 5.75 | 5.87 |
| 9 | Grenzbach | 17.04.96 | * | 8.2 | * | 7.1 | * | · | * | 4.62 |
| | | 06.05.96 | | 8.2 | | 8.0 | | 378 | | 3.33 |
| | | 04.07.96 | | 4.8 | | 13.8 | | · | | 2.79 |
| | | 30.08.96 | | 5.7 | | 12.6 | | 400 | | 3.27 |
| | | 05.11.96 | | 5.66 | | 9.7 | | 403 | | 3.05 |
| 8 | Deubitzwiesen | 17.04.96 | * | 7.4 | * | 6.1 | * | · | * | 4.18 |
| | | 06.05.96 | | 9.16 | | 11.0 | | 310 | | 4.07 |
| | | 04.07.96 | | 6.43 | | 16.1 | | · | | 3.44 |
| | | 30.08.96 | | 8.43 | | 14.3 | | 303 | | 3.65 |
| | | 05.11.96 | | 7.71 | | 9.9 | | 299 | | 3.7 |

· = no measurements, * = spring not defined; ** = site number corresponding to Figure 1.

the field with electronic instruments: conductivity with Lf96B, temperature and oxygen (saturation and mg/l) with Oxi 320, pH with pH95 of WTW Ltd.

The surface chironomid fauna were sampled using a hand net ('Thienemann-Kescher') (mesh size 250 μm). The net was pulled for 10 min along a stretch of about 30 m through the water surface of the brook to obtain surface drift, mainly pupal exuviae, some adults, and larvae. In the spring mouth, the net was pulled through all compartments of the aquatic area with great care in order not to destroy the habitat. The chironomids were sorted in the field from other material caught with the net and preserved in 70% isopropanol. The taxa were identified, after preparation in Euparal, mainly with the works of Langton (1991) and Wiederholm (1983, 1986, 1989), individual papers on taxonomy, and the use of a reference collection. Abundances were estimated in 7 classes (1 = 1; 2 = 2– 4; 3 = 5–15; 4 = 16–32; 5 = 33–74; 6 = 75–150; 7 = > 150 specimens per sample).

The data for other spring brooks of the region (Ochsenkopf 1, Parnitz, Heidemühle, Ausreisser, Taura, Lausa), published elsewhere (Orendt 1998), were included in the evaluation.

The references for the ecological characters used in Table 3 (i.e. crenophilic, cold-stenothermic etc.) are Wiederholm (1983), Fittkau (1962), Fittkau and Reiss (1978), Moog (1995), Reiss (1969) and Sæther (1990).

## Results

### *Abiotic factors*

The pH measurements (Figure 2) show clearly that the water bodies could be differentiated into fairly acid

*Table 2.* Some characters of the water bodies studied; * = data from Orendt (1998), ** = site number corresponding to Figure 1, n.d. = not determined.

| Site no.** | Site | Water type | | Dominant vegetation | pH | Cond. (µS/cm) | Temp. (°C) | $O_2$ (mg/l) | Taxa (*N*) | Crenophilic species (*N*) |
|---|---|---|---|---|---|---|---|---|---|---|
| 10 | Ausreisser* | Brook | Permanent | *Pinus* spp. | 3.80–6.89 | 206–477 | 6.3–18.7 | n.d. | 27 | 4 |
| 4 | Breitewitzer Bach | Spring brook | Temporary | *Pinus* spp. | 6.24–6.77 | 226–260 | 9.8–11.0 | 2.18–4.65 | 10 | 2 |
| 4 | Breitewitzer Bach/ spring | Spring (rheocrene) | Temporary | *Pinus* spp. | 6.11–6.74 | 226–260 | 9.6–10.9 | 0.37–1.25 | 1 | 0 |
| 8 | Deubitzwiesen | ditch | Permanent | *Fagus sylvatica* | 3.44–4.18 | 299–310 | 6.1–16.1 | 6.43–9.16 | 13 | 4 |
| 9 | Grenzbach | ditch | Permanent | *Pinus* spp. | 2.79–4.62 | 378–403 | 7.1–13.8 | 4.80–8.20 | 5 | 2 |
| 5 | Heidemühle* | Brook | Permanent | *Pinus* spp., *Alnus glutinosa* | 3.87–6.41 | 145–346 | 3.2–19.2 | n.d. | 28 | 5 |
| 12 | Lausa* | Brook/ditch | Permanent | *Fagus sylvatica*, *Pinus* spp. | 3.36–5.58 | 172–695 | 0.2–17.8 | n.d. | 6 | 3 |
| 7 | Lutherstein | Spring brook | Permanent | *Pinus* spp., *Fagus sylvatica*, *Alnus glutinosa*, *Betula pendula* | 5.45–5.87 | 54–87 | 10.3–12.2 | 4.59–7.88 | 12 | 3 |
| 7 | Lutherstein/spring | Spring (helocrene) | Permanent | *Pinus* spp., *Fagus sylvatica*, *Alnus glutinosa*, *Betula pendula* | 4.55–5.32 | 19–155 | 7.8–14.5 | 1.45–2.95 | 3 | 0 |
| 6 | Mark Schmelz | Spring brook | Permanent | *Fagus sylvatica*, *Alnus glutinosa* | 5.69–6.35 | 168–179 | 9.9–11.2 | 4.63–7.55 | 9 | 2 |
| 6 | Mark Schmelz/ spring | Spring (rheo-helocrene) | Permanent | *Fagus sylvatica*, *Alnus glutinosa* | 5.62–5.97 | 161–173 | 9.2–11.8 | 0.36–0.49 | 0 | 0 |
| 1 | Ochsenkopf 1* | Spring brook | Permanent | *Fagus sylvatica* | 5.51–6.67 | 160–293 | 3.5–15.4 | n.d. | 11 | 0 |
| 2 | Ochsenkopf 2 | Spring brook | Permanent | *Alnus glutinosa*, *Fagus sylvatica*, *Betula pendula*, *Pinus* spp. | 5.64–6.52 | 267–268 | 9.7–14.2 | 4.65–8.98 | 21 | 4 |
| 2 | Ochsenkopf 2/ spring | Spring (helocrene) | Permanent | *Alnus glutinosa* | 5.66–6.10 | 268–294 | 9.7–10.5 | 0.13–2.44 | 7 | 0 |
| 3 | Parnitz* | Spring brook | Permanent | *Alnus glutinosa* | 5.95–6.89 | 369–534 | 1.9–18.7 | n.d. | 8 | 3 |

*Table 3.* Records and abundances of chironomid taxa of springs and spring brooks of the Dübener and Dahlener Heide with remarks on their ecology (according to the references given in the Methods section) and the indication of the developmental stage on which the taxa were identified.

| Taxon | Ecology | Stage | Sample site no.** | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Springs | | | Spring brooks | | | | | Ditches | | | Brooks | | | |
| | | | 4 | 7 | 2 | 4 | 7 | 6 | 2 | 3* | 8 | 9 | 12* | 10* | 5* | 1* | 11* |
| | | *** | . | . | (r)c | qrc | qrc | qrc | qrc | rqc | qrc | qc | qc | qrc | qrc | r(c) | qrc |
| Tanypodinae | | | | | | | | | | | | | | | | | |
| *Apsectrotanypus triascipennis* (Zetterstedt) | r | L, P | . | . | . | . | . | . | . | 1 | . | . | . | 1 | . | . | . |
| *Conchapelopia* sp. | | L | . | . | . | . | . | . | . | . | . | . | . | 2 | . | . | . |
| *Krenopelopia* sp. | cq | L | . | . | 1 | . | . | . | . | . | . | . | . | . | . | . | . |
| *Macropelopia adaucta* (Kieffer) | cqa | P, L | . | . | . | . | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | . | 2 |
| *Macropelopia notata* (Meigen) | cqa | P, Pu | . | . | . | . | . | . | . | 1 | . | . | . | . | . | . | 2 |
| *Macropelopia notata* grp. | | L | . | . | . | . | . | . | . | . | . | . | . | 1 | . | . | . |
| *Macropelopia* sp. | | L | . | 2 | 2 | . | 2 | . | . | . | . | . | 1 | 2 | 2 | . | 2 |
| *Trissopelopia longimana* (Staeger) | cr | P | . | . | . | . | 1 | 1 | 1 | 1 | . | . | . | . | . | . | . |
| *Trissopelopia* sp. | cr | L | . | . | . | . | . | . | . | . | . | . | . | . | 2 | . | . |
| *Zaverlimyia* sp. | (c) | L | . | . | . | . | . | . | . | . | . | . | . | . | 1 | 2 | . |
| Prodiamesinae | | | | | | | | | | | | | | | | | |
| *Prodiamesa olivacea* (Meigen) | | P, Le, L | . | 2 | 2 | . | 2 | 2 | 2 | . | . | . | . | . | 1 | 1 | . |
| Orthocladiinae | | | | | | | | | | | | | | | | | |
| *Brillia bifida* (Kieffer) | r | L, Le, P | . | . | . | 3 | 2 | 2 | 3 | 2 | . | . | . | 2 | 2 | . | . |
| *Camptocladius stercorarius* (De Geer) | Semiaqu. | I | . | . | . | . | . | . | . | . | 1 | . | . | . | . | . | . |
| *Chaetocladius perennis* (Meigen) | r | P | . | . | . | . | . | . | . | . | . | . | . | 2 | . | 1 | . |
| *Chaetocladius piger* (Goetghebuer) | rq | I | . | . | . | . | . | . | . | . | . | . | . | . | 1 | . | 1 |
| ?*Chaetocladius* sp. (juv.) | | L | 1 | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Corynoneura* Pe2a (Langton 1991) | r | P | . | . | . | . | . | . | . | . | . | . | . | 2 | 2 | . | . |
| *Corynoneura* cf. *lobata* (Edwards) | qr | P | . | . | . | . | . | . | . | . | . | . | . | . | 2 | . | 2 |
| *Corynoneura* cf. *scutellata* (Winnerts) | | P | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 3 |
| *Corynoneura coronata* (Edwards) | | P | . | . | . | . | . | . | . | . | 4 | 1 | . | . | . | . | . |
| *Corynoneura fittkaui* (Schlee) | qa | I, P | . | . | . | . | . | . | . | . | . | . | 2 | . | . | . | 4 |
| *Corynoneura* sp. | | L | . | . | . | . | . | . | 3 | . | 2 | . | 2 | . | 2 | . | 2 |
| *Corynoneura* sp. A (Cranston 1982) | | L | . | . | . | . | . | . | . | . | . | . | . | 2 | . | . | . |
| *Cricotopus (C.)* Pe8 (Langton 1991) | | P | . | . | . | . | . | . | 2 | . | . | . | . | . | . | . | . |
| *Eukiefferiella brevicalcar* (Kieffer) | r | P | . | . | . | . | 2 | . | 3 | . | . | . | . | 1 | . | 2 | . |
| *Eukiefferiella claripennis* grp. | | L | . | . | . | . | . | . | . | . | . | . | . | . | . | 2 | . |
| *Eukiefferiella coerulescens* grp. | | L | . | . | . | . | . | . | . | . | . | . | . | . | 1 | . | . |
| *Eukiefferiella gracei* (Edwards) | r | P | . | . | . | . | . | . | . | . | . | . | . | . | 2 | . | . |
| *Eukiefferiella gracei*-Gr. | | L | . | . | . | . | . | . | . | . | . | . | . | 2 | . | . | . |
| *Eukiefferiella* sp. | | L | . | . | . | 2 | . | . | 2 | . | . | . | . | . | . | 2 | . |
| *Heleniella ornaticollis* (Edwards) | r | P | . | . | . | . | . | . | 1 | . | . | . | . | . | . | . | . |
| *Heterotanytarsus apicalis* (Kieffer) | c | P | . | . | . | . | . | 1 | . | . | . | . | . | 2 | 2 | 1 | . |

*Table 3. continued.*

| Taxon | Ecology | Stage | Sample site no.** | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Springs | | | Spring brooks | | | | | Ditches | | | Brooks | | | |
| | | | 4 | 7 | 2 | 4 | 7 | 6 | 2 | 3* | 8 | 9 | 12* | 10* | 5* | 1* | 11* |
| *Heterotanytarsus* sp. | | L | . | . | . | 1 | . | . | . | . | . | . | . | 1 | . | . | . |
| *Heterotrissocladius marcidus* (Walker) | c | I, P, L, Le | . | . | 3 | 2 | 2 | 3 | 2 | . | 2 | . | . | 3 | 4 | . | 2 |
| *Heterotrissocladius marcidus* grp. | | L | . | . | . | . | . | . | . | 1 | . | . | . | 2 | . | . | . |
| *Limnophyes* Pe1a (Langton 1991) | | P | . | . | . | . | . | . | . | . | . | . | 2 | . | . | . | 2 |
| *Limnophyes minimus* (Meigen) | Semiaqu. | I, P | . | . | . | . | . | . | . | . | 2 | 2 | . | . | . | . | 1 |
| *Limnophyes punctipennis* (Goetghebuer) | Terrestr. | P | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 2 |
| *Limnophyes* sp. | | L | . | . | . | . | . | . | . | . | . | 2 | . | 1 | . | . | 2 |
| *Orthocladius (Symposiocladius) lignicola* (Kieffer) | w | P | . | . | 2 | . | . | . | . | . | . | . | . | . | . | . | . |
| *Orthocladius* sp. | | I | . | . | . | . | . | . | . | . | 2 | . | . | . | . | . | . |
| *Parametriocnemus* sp. | r | L | . | . | . | . | . | . | . | . | . | . | . | 2 | 2 | . | . |
| *Parametriocnemus boreoalpinus* (Gowin) | r | P | . | . | 1 | . | . | . | . | . | . | . | . | . | . | . | . |
| *Parorthocladius nudipennis* (Kieffer) | rc | P | . | . | . | . | . | . | . | . | 1 | . | . | . | . | . | . |
| *Paratrissocladius excerptus* (Walker) | r | P | . | . | . | . | . | . | 1 | . | . | . | . | . | . | . | . |
| *Psectrocladius* sp. | | L | . | . | . | . | . | . | 2 | . | . | . | . | . | . | . | . |
| *Psectrocladius bisetus* (Goetghebuer) | qa | P | . | . | . | . | . | . | . | . | 1 | . | . | . | . | . | . |
| *Pseudorthocladius virgatus* grp. | | L | . | . | . | . | . | . | . | 2 | . | . | . | . | 2 | . | . |
| *Pseudorthocladius curticosta* | Semiaqu. | P | . | . | . | . | . | . | . | . | . | . | . | . | 2 | . | . |
| *Rheocricotopus (R.) fuscipes* (Kieffer) | r | P | . | . | . | 1 | . | . | 2 | . | . | . | . | . | . | 1 | . |
| *Rheocricotopus (Ps.) glabricollis* (Meigen) | rq | P | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 |
| *Smittia* cf. *leucopogon* | Semiaqu. | I | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 |
| Chironominea/Chironomini | | | | | | | | | | | | | | | | | |
| *Chironomus luridus* (Strenzke) | Tempor. | I, P | . | . | . | . | . | 1 | . | . | . | . | . | . | . | . | 3 |
| *Chironomus riparius* (Meigen)/ *piger* (Strenzke) | | P | . | . | . | . | . | 1 | . | . | . | . | . | . | . | . | . |
| *Polypedilum albicorne* (Meigen) | cqr | I, P | . | . | . | 3 | 3 | 3 | 3 | 2 | . | . | . | 2 | 2 | . | . |
| *Polypedilum pedestre* (Meigen) | r | P | . | . | . | . | . | . | 1 | . | . | . | . | . | 1 | . | . |
| *Polypedilum pullum* (Zetterstedt) | | I | . | . | . | . | 1 | . | . | . | . | . | . | . | . | 2 | . |
| *Polypedilum* sp. | | L | . | . | . | . | 2 | . | . | . | . | . | . | . | . | 2 | . |
| *Polypedilum tritum* (Walker) | r | I | . | . | . | 1 | . | . | 2 | . | . | . | . | 2 | . | . | 2 |
| Chironominea/Tanytarsini | | | | | | | | | | | | | | | | | |
| *Micropsectra* Pe1/*notescens* (Walker) | | P | . | . | . | . | . | . | . | . | . | . | . | . | 4 | . | . |
| *Micropsectra atrofasciata* agg. | r | P | . | . | . | 1 | 1 | . | . | . | 1 | . | . | 3 | 2 | . | 1 |
| *Micropsectra bidenta* (Goetghebuer) | rc | I, P | . | . | . | . | . | . | . | . | . | . | . | 3 | 1 | . | 2 |

*Table 3. continued.*

| Taxon | Ecology | Stage | Sample site no.** | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Springs | | | Spring brooks | | | | | Ditches | | | Brooks | | | |
| | | | 4 | 7 | 2 | 4 | 7 | 6 | 2 | 3* | 8 | 9 | 12* | 10* | 5* | 1* | 11* |
| *Micropsectra contracta* (Riess)/ *apposita* (Walker) | r | P | . | . | . | . | . | . | 2 | . | . | . | . | 1 | . | . | . |
| *Micropsectra fusca* (Meigen) | cq | P | . | . | . | 2 | 2 | . | 2 | . | . | . | . | 3 | 2 | . | 2 |
| *Micropsectra lindebergi* (Säwedal)/ *insignilobus* (Kieffer) | | P | . | . | 1 | . | . | 1 | 2 | . | . | . | . | . | . | . | . |
| | | *** | . | . | rc | qrc | qrc | qrc | qrc | rqc | qrc | qc | qc | qrc | qrc | r(c) | qrc |
| *Micropsectra notescens* (Walker) | cr | P | . | . | . | . | . | . | . | . | . | . | . | . | 1 | . | . |
| *Micropsectra* sp. | | L | . | 2 | . | . | . | . | . | . | . | . | . | 3 | . | 2 | . |
| *Parapsectra uliginosa* Reiss | ca | P | . | . | . | . | . | . | 1 | . | . | . | . | . | 1 | . | . |
| *Stempellina bausei* (Kieffer) | | P | . | . | . | . | . | . | 1 | . | . | . | . | . | . | . | . |
| *Stempellinella flavidula* (Edwards) | r(c) | P | . | . | . | . | . | . | . | . | . | . | . | 1 | . | . | . |
| *Tanytarsus buchonius* (Reiss & Fittkau) | q | P | . | . | . | . | . | . | . | . | 4 | 1 | 1 | 2 | 2 | . | 3 |
| *Tanytarsus* Pe15 (Langton 1991) | | P | . | . | . | . | . | . | . | . | . | . | . | 1 | 2 | . | . |
| *Tanytarsus* cf. *signatus* (van der Wulp) | (q) | I | . | . | . | . | . | . | . | . | 1 | . | . | . | . | . | . |
| *Tanytarsus* sp. | | L | . | . | . | 1 | . | . | . | . | 1 | . | . | . | 1 | . | 3 |

* = data from Orendt (1998); ** = corresponding to Figure 1. *** = ecotypes of the taxa found in waters. Abundances in classes from 1 (= single specimen) to 7 (= >150 specimens; see section '3 Methods'). As no specimen was recorded from the spring of Mark Schmelz, the site is not included in the list. *Abbreviations:* a = acidophilic, c = cold-stenothermic,w = wood mining, r = rheophilic, q = crenophilic, semiaqu.= semiaquatic, tempor. = temporary water bodies, terrestr. = terrestrial. L = larva, P = pupal exuvia, Pu = pupa, I = imago. n.d. = no data. 1 = Ochsenkopf 1, 2 = Ochsenkopf 2, 3 = Parnitz, 4 = Breitewitzer Bach, 5 = Heidemühle, 6 = Mark Schmelz, 7 = Lutherstein, 8 = Deubitzwiesen, 9 = Grenzbach, 10 = Ausreisser, 11 = Taura, 12 = Lausa.

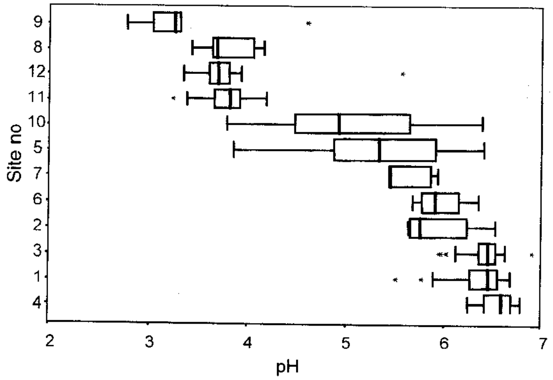


*Figure 2.* Box-and-whisker plot of the pH of the spring brooks investigated; ∗ = outliers (values differing greatly from the other values). The numbers correspond to the sites as indicated in the legend of Figure 1.

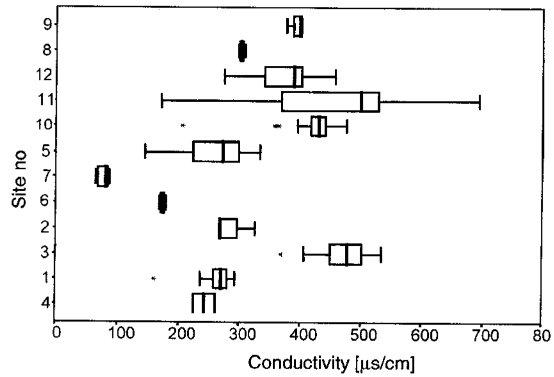


*Figure 3.* Box-and-whisker plot of the conductivities of the spring brooks investigated. ∗ = outliers (values differing greatly from the other values). The numbers correspond to the sites as indicated in the legend of Figure 1.

ones (Grenzbach, Deubitzwiesen, Taura, Lausa), moderately acid (Lutherstein, Heidemühle, Ausreisser) and subneutral and neutral water bodies (Mark Schmelz, Breitewitzer Bach, Ochsenkopf 1 and 2). The most acid conditions were found in the source of the Grenzbach Brook, where the pH values were significantly lower than even the permanently acid brooks Deubitzwiesen, Taura and Lausa ($p < 0.05$; Mann–Whitney test). The minimum pH measured there was 2.79 on 4 July 1996. The highest value (6.89) was recorded at Parnitz on 22 March 1994. The pH distribution displays a relatively heterogeneous pattern in the northern part of the study area, where highly acid and neutral or subneutral brooks are situated very close together. The conductivity distribution was also heterogeneous (Figure 3), but not congruent with the pH distribution. In the spring brooks, the lowest values were recorded at Lutherstein (64 µS/cm), the highest in Taura (695 µS/cm). At the latter site, the variation between the values at different sampling dates was high, ranging from 172 to 695 µS/cm. The comparison of the values at Lutherstein between the spring mouth and the brook about 30 m downstream (Table 1) demonstrates the heterogeneity of even short reaches of spring water bodies. These results appear to reflect a mosaic of pedological and geological types within a relatively small area in this diverse glacial landscape.

At the spring mouth and just beyond, oxygen levels often dropped below 10% (1 mg/l; Table 1). In water bodies with very low flow (< 1 l/s; Deubitzwiesen, Grenzbach), oxygen saturation levels of up to 84% were found, higher than in those with faster velocities.

Similar differences between low and faster flowing water bodies were displayed for water temperature (Table 1). Water bodies with low flow (Deubitzwiesen, Grenzbach, spring region of Lutherstein) were hotter in warm seasons and colder in cold seasons than in the faster flowing brooks, where the temperature measured in all seasons was around 10–12°C. In the brooks with faster flow, differences between the spring mouth and the reaches 30–50 m downstream were insignificant.

These patterns of physico-chemical properties demonstrate the diversity of the water bodies.

*Communities*

A total of 74 chironomid taxa were recorded (Table 2). The highest diversity was found in the brooks at Heidemühle ($N = 27$) and Ausreisser ($N = 26$), which have been identified as permanently acidified water bodies (Orendt 1998; Orendt & Reinhart 1998) based on the occurrence of acid-tolerant and acid-sensitive macroinvertebrate taxa (see Braukmann 1992). However, the lowest numbers were also observed in permanently acidic water bodies (Lausa: $N = 6$, Grenzbach: $N = 5$). In neutral and subneutral water bodies the taxa numbers ranged from 10 to 20. In spring regions (Ochsenkopf 2, Breitewitzer Bach, Lutherstein) very few chironomids were obtained. Except for Ochsenkopf 2, no pupal exuviae were found, only larvae. In the spring of Mark Schmelz, no chironomids were recorded.

Taxonomic diversity did not correlate significantly with pH nor with conductivity (Kendall's rank correlation of taxa number with the medians of the parameters mentioned). Correlations with temperature and oxygen were not performed here, because of a lack of comparable data: temperature was measured weekly in

1993/94 (Orendt 1998), but only occasionally in 1996 (Table 1); oxygen was measured in 1996 (Table 1), but not in 1993/94. For the four sites measured, diversity was always higher in the spring brook than in the spring upstream, which corresponded with the distribution of the oxygen concentrations (Table 4). However, the correlations were at a weak level of significance ($p < 0.1$), as the number of sites was low ($N = 4$; Wilcoxon test). On the other hand, the correlation between taxa diversity and oxygen concentrations (from all sites) was more significant ($p < 0.05$; Kendall's $\tau$).

The chironomid communities of most sites are characterized by the presence of rheophilic, cold-stenothermic and crenophilic elements (Table 3, Figure 4). Frequent representatives of those species were e.g. *Macropelopia adaucta* (crenophilic, cold-stenothermic and rheophilic), *Heterotrissocladius marcidus*, *Heterotanytarsus apicalis*, *Trissopelopia* sp. (cold-stenothermic). In most water bodies, at least one crenobiontic or crenophilic species was recorded. However, in three springs (Ochsenkopf 2/spring, Breitewitzer Bach/spring and Lutherstein/spring) none of crenophilic species were found. Some prefer peatland water bodies (tyrphophilic), e.g. *Parapsectra uliginosa* (Reiss 1969), *Psectrocladius bisetus* (Reiss 1982), *Corynoneura fittkaui* (Janecek *et al.* 1995), *Heterotanytarsus apicalis* (Fittkau and Reiss 1978), *Macropelopia notata*, *M. adaucta* (Fittkau 1962). Thus,

*Table 4.* Oxygen concentrations (average) and taxonomic diversity in some brooks and their springs.

| Site | Brook | | Spring | |
|---|---|---|---|---|
| | $O_2$ (mg/l) | Taxa (*N*) | $O_2$ (mg/l) | Taxa (*N*) |
| Lutherstein | 7.04 | 12 | 1.92 | 3 |
| Breitewitzer Bach | 2.44 | 10 | 0.64 | 1 |
| Ochsenkopf 2 | 6.35 | 21 | 1.72 | 7 |
| Mark Schmelz | 4.70 | 10 | 0.46 | 0 |

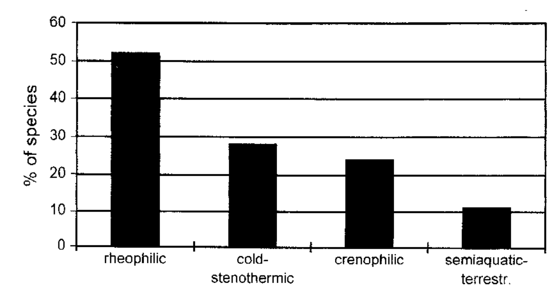


*Figure 4.* The portions of the different ecotypes in the woodland brooks investigated (*n* of species = 46). Only taxa on species or 'cf.' level from Table 3 were used.

the brooks were characterized by a community including crenophilic, cold-stenothermic, rheophilic and tyrphophilic specialists (Figure 4).

## Discussion

The low concentrations of oxygen in the springs and the low variability in water temperatures (Table 1) indicate that water emerged from groundwater layers (except at Deubitzwiesen and Grenzbach, where higher oxygen contents indicate that water derived from the upper soil layers). Water temperatures did not rise significantly in the spring brook (i.e. 30–40 m downstream of the spring) but oxygen concentrations increased in turbulent contact with the air. These concentrations are quite low compared to the measurements of Thorup and Lindegaard (1977) in Danish springs (70–100% saturated), Wagensonner (1992) and Schirmer (1990) in prealpine limnocrenes (> 50%) or Gerecke (not published) in alpine springs and spring brooks (> 90%). Lindegaard (1995) assumes that low oxygen concentration in the springs is responsible for the low richness or absence of species. This corresponds to the findings of this study, with lower oxygen concentrations and fewer taxa found in the spring than in the spring brook (Table 4). Equally, algal and bacterial productivity and, as a consequence, nourishment for insects, is low in springs, because groundwater commonly contains low concentrations of nitrogen and phosphorus (van der Kamp 1995). However, in the spring of Ochsenkopf 2, among others, the presence of the wood mining *Orthocladius* (*Symposiocladius*) *lignicola* indicates that the quality and characteristics of the water column are not the only factors which determine the nature of the community, but that substrate also plays a role. Thus, mainly species which are particularly adapted can live in this habitat and only in low abundances (as recorded in the springs of Ochsenkopf 2, Breitewitzer Bach, Lutherstein). However, some of these species were recorded also from the downstream reaches. Ubiquitous species were not absent (e.g. *Prodiamesa olivacea*). Thus, for chironomids, the fauna recorded in the spring mouth and the very near surroundings themselves can not be called creno*biontic* but instead creno*philic*, as it can be found also in the spring brooks and groundwater fed ditches. This corresponds with the general conclusions of Lindegaard (1995). The latter noted that *Corynoneura fittkaui* is recorded as the only chironomid which is strictly limited to springs (creno*biontic*), while all other species also occur in the downstream reaches and sometimes in other habitats, and therefore have to be termed as creno*philic*. A high number of the species which are considered as crenophilic occur in the investigated spring brook reaches. *C. fittkaui* was found in two rivulets which were considered as brooks showing that strict separation of spring and spring brook communities or groundwater fed ditch communities is quite difficult. The system should be considered as a mosaic ecosystem without strict limitations.

In this study, no significant correlations were found between the presence or abundance of the species and pH values or conductivity. Perhaps, this may be due to the small number of samples which reduces the level of significance. Using PCA, Orendt (1999) found that a gradient exists in the composition and structure of chironomid communities between the acidic and neutral streams within the study area. Simpson (1983) and Leuven *et al.* (1987) also have shown that the species number declined with increasing acidity. This appears to be characteristic for moderate latitudes, since Cranston *et al.* (1997) found an increasing species richness with declining pH in tropical streams.

It may be claimed that the results of this study are an outcome of an inappropriate methodology, as only drift was sampled, few samples were taken, and a relatively high number of single specimen taxa was recorded. That may be underlined by the fact that few species were recorded from the spring regions. No chironomids were found at the Mark Schmelz spring, although this does not imply that chironomids are not present there. Although the spring areas were very small (about 30 cm × 30 cm), a strong differentiation between spring and spring brook (10 m downstream) was apparent from the oxygen concentration measured (Table 1). Perhaps sampling of larval material in the benthos would have yielded more chironomids. However, the small extent of the habitat at this site did not allow sufficient sampling without damaging the spring mouth area severely. Moreover, chironomid larvae are much more difficult to determine at a species level (impossible in many genera) leading to a much less precise characterisation of the community. This was found in earlier investigations in spring brooks and springs (Orendt 1998; Orendt, in press), when both larvae and pupal exuviae were sampled. As the intention of the study was to survey the chironomid fauna on *species level*, it was decided to take only samples from the surface drift to receive pupal exuviae. Moreover, by sampling the species inhabiting a range of microhabitats, the technique ensured that these microhabitats were not overlooked, which could easily occur when benthos is sampled exclusively. However, the small number of specimens caught from the spring regions in this investigation suggests that several more samples should be taken to represent the chironomid spring community more clearly. On the other hand, the results are consistent with general patterns observed: in most spring systems diversity increases from the mouth to the lower reaches of the following brook (Lindegaard 1995); only in exceptional and very special cases is the reverse true, as referred to by Resh (1983) for warm springs. The various single record species are chracteristic of the habitat and should therefore not be neglected as 'strays' (e.g. the crenophilic and cold-stenothermic *Parapsectra uliginosa* in the Ochsenkopf 2 spring brook and Heidemühle brook, the crenophilic *Krenopelopia* sp. in Ochsenkopf 2 spring, the semi-aquatic *Camptocladius stercorarius* in the groundwater-influenced Deubitzwiesen ditch).

The system 'spring– spring brook' is an ecotone with a high variability of characters, so that each system considered in this study presents itself as an individual both in abiotic and biotic terms. Both aspects emphasize the value of these systems for conservation.

## Conservation aspects and conclusions

In general, the species found in this study serve as indicators for changes in landscape character. They show whether typical elements of a lowland landscape (like spring-influenced water bodies in woodland) decrease and how fast they do so. As crenophilic, cold-stenothermic and rheophilic specialists are prominent inhabitants of the brook communities presented in this paper, they are representative of some of the most endangered landform elements in central Europe, consisting not only of springs, but running water bodies and peatlands as well. The habitats containing this specialized fauna are situated only in forested areas. Outside the forest, nearly all springs and semi-natural reaches of running water bodies are destroyed and channelled in underground pipes. It is, therefore, obvious that these woodland water bodies deserve the highest priority for protection of the spring communities presented. They represent the last refuges for the characteristic crenophilic fauna in this highly impacted region.

Beside the Chironomidae, it is known for other taxonomic groups that increased acid concentrations affect the behavior of certain taxa (e.g. Matthias 1983; Townsend *et al.* 1983; Weatherly *et al.* 1990; Orendt & Reinhart 1998). Orendt (1999) recorded the sensitivity of certain chironomid species to acid and classified several species presented in this paper as extremely and moderately sensitive to acid. Increased acidification will cause the extinction of these species from their habitats. Modified behavior (e.g. drifting, higher ventilation activity of the gills) caused by extreme abiotic conditions (e.g. low pH) endangers the fitness of a species in its habitat. Orendt (1998) documented high concentrations of dissolved sulphate near power plants indicating that acidification derived from industrial activity (acid depositions) rather than from a natural process. This implies that the protection of spring systems from physical destruction is not enough to prevent a loss of biodiversity, as the impact of fallout material like acid and fly ashes derived from industrial activities changes the environment for the community.

Another important threatening factor may be the hydrological regime on which the community depends. A reduction of groundwater flow causes desiccation of the spring. This may cause all functions of the habitat complex to cease (on 5th of November 1996 the brook and its spring was dried out at Breitewitzer Bach).

Therefore, only an interdisciplinary conservation strategy which integrates measures on agricultural, forestry, hydrological and socio-economic levels and at different scales can decrease the threat to the small brook ecosystem. The brook community is very sensitive to changes in environmental conditions (any of the main parameters) and thus serves as an indicator for changes in landscape functions. However, intact spring and spring brook complexes need to be available as a reference and these should, therefore, be conserved with high priority.

## Acknowledgements

I wish to thank P. Langton for help in taxonomic questions, and for the discussion of the results, to H.V. Danks for valuable comments on the manuscript and to T. Zoete for the revision of the English language. The study was sponsored by the Saxonian Ministry of Science and Art, Dresden.

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