

Effects of acid atmospheric deposition on chemistry and benthic macroinvertebrates of forest streams in the Brdy Mts (Czech Republic)

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Abstract. Water chemistry and macroinvertebrates of 8 streams in the Brdy Mts (Central Bohemia) differing in pH value were studied during a synoptic survey in December 1997. Together 73 macroinvertebrate taxa were identified, varying in number from 9–25 at sites of critical pH (3.8–4.3), contrary to 25–28 taxa at non-acidified sites (pH around 6.7). The fauna of streams was dominated by Chironomidae (Diptera) and Plecoptera, Trichoptera were less abundant. In three strongly acidified streams the predominance of Plecoptera exceeded 50% of all macroinvertebrates. The absence of some aquatic insects (like e.g. Ephemeroptera, some Trichoptera, most Diptera, and some Plecoptera) at sites with pH < 4.8 is discussed. The streams were classified according to their macroinvertebrate communities, with use of the Jaccard index of similarity. *Symposiocladius lignicola* (Kieffer, 1915) (Diptera: Chironomidae) is reported from Bohemia for the first time.

Acidification, running waters, winter season, water chemistry, benthic fauna, macroinvertebrates, Czech Republic, Palaearctic region

INTRODUCTION

The majority of the regional knowledge concerning processes of anthropogenic surface water acidification and its effects on biota is associated with the studies in the mountains on the borders of the former Czechoslovakia. The high mountain lakes in the Tatra Mts (Kopáček et al. 2000), the forest lakes in the Bohemian Forest (Veselý et al. 1998, Vrba et al. 2002), mountain drinking water reservoirs in the Jizera Mts (Stuchlík et al. 1997) and some streams in the Ore Mts (Krám & Hruška 1994) have been intensively studied for more than 20 years, providing detailed information about the impact of acid deposition on freshwater ecosystems. The response of plankton communities to pH changes was investigated, including the response to oligotrophication and the toxic role of aluminium in particular (Fott et al. 1994).

The Brdy Mts situated in Central Bohemia have been historically known as an area rich in large peat bogs, but their sensitivity to acid deposition was not elucidated until a detailed water chemistry survey performed in 1984 (Veselý & Majer 1996). Surface waters of this area, represented mostly by brooks and drinking water reservoirs, exhibit mean pH values lower than 5.5, indicating

This contribution is dedicated to Doc. RNDr. Jaroslav Hrbáček DrSc., upon the occasion of the 80th anniversary of his birthday (12th May 1921).

that the Brdy Mts are among the regions of the Czech Republic which were the most intensively impacted by acid atmospheric deposition (Veselý & Majer 1998).

While the effect of acidification on the macroinvertebrates of running waters in Europe and North America is generally well documented (e.g., Hall & Ide 1987, Weatherley et al. 1989, Mulholland et al. 1992, Herrmann et al. 1993, Guerold et al. 1995, Lien et al. 1996, Orendt 1998, Szczęsny 1998), there is a lack of such information from the Czech Republic and only several limited studies have been published so far (Růžicková 1998, Scheibová & Helešic 1999).

Our knowledge on the benthic invertebrate fauna of the Brdy Mts is rather fragmentary, as the possibility of field research has been limited due to the existence of a military area in this region since 1926. One of the first records of the Brdy Mts freshwater organisms were presented at the

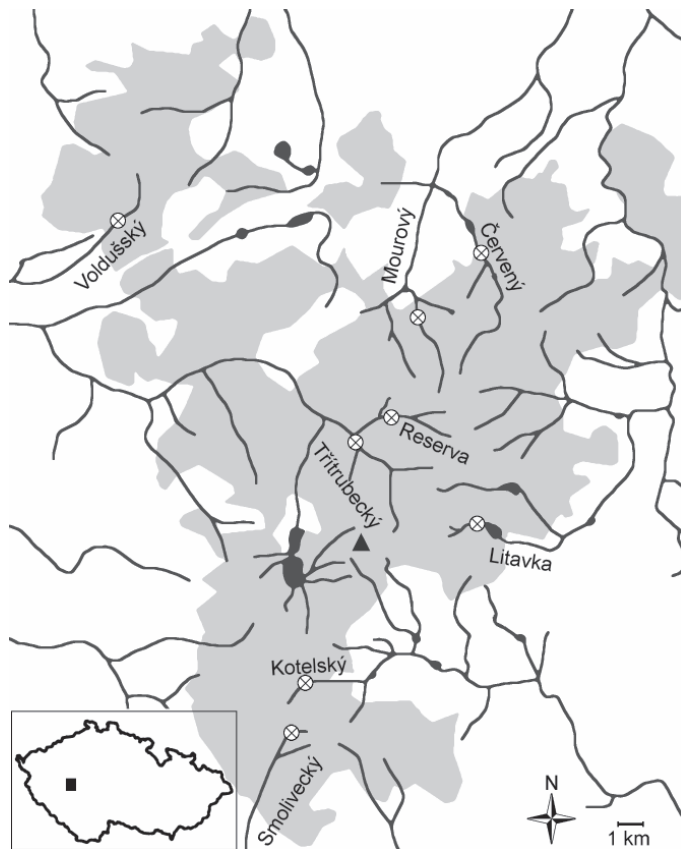


Fig. 1. Stream system of the Brdy Mts with the sampling sites. ⊗ – sampling site, triangle – Nepomuk precipitation station.

beginning of the 20th century by Roubal & Štorkán (1924). Basic information on the fauna of Ephemeroptera, Plecoptera and Trichoptera were obtained thanks to long-term research of several streams in the Brdy Mts (mainly at lower altitudes) in the late 1950s (Křelinová 1962, Novák 1962, pers. comm., Landa & Soldán 1989) and only a single site was sampled in the mid-1990s again (Soldán et al. 1998). Results of a hydrobiological study directed to small streams in the central part of the Brdy Mts including a brief list of macroinvertebrate genera were published by Pivnička et al. (1993).

The main aim of this pilot study is to recognise the impact of acid atmospheric deposition on water chemistry, species composition and diversity of benthic fauna in several brooks of these mountains.

SITES AND METHODS

Study area

The Brdy Mts (49° 32' N, 13° 42' E – 49° 50' N, 14° 05' E) represent the largest forested complex in the central part of the Czech Republic being situated in the Labe basin, about 50 km SW of Prague (Fig. 1). The maximum altitude of the mountain range is 864.9 m a. s. l. and the altitude of our study sites ranges from 470–685 m a. s. l. (according to base maps 1:50 000 – Mašek 1990). The Brdy Mts are covered mostly by spruce (*Picea abies*) forests and peat bogs are frequent in spring areas.

The geology of the Brdy Mts is dominated by cambrian sandstone, conglomerates, and quartzites. These rocks, with a low content of calcium and other nutrients, form nutrient-poor brown soils that tend to form high moor bogs at the highest flat altitudes. Brown soils relatively rich in nutrients occur locally, especially in the north-west mountain part where late Variscan granodiorites and diabase vulcanites encroach. The southern part contains Middle Proterozoic shales and greywackes with numerous phthanitic intercalations (Petříček & Dejmal 1998, Havlíček 1986, Mašek, 1990).

Eight sites comparable in vegetation but varying in stream size, pH and altitude were selected on the following brooks: Voldušský (VOL), Červený (CER), Mourový (MOU), Reserva (RES), Třítrubecký (TRI), Kotelský (KOT), Smolivecký (SMO) and Litavka (LIT) (Tab. 1, Fig. 1). Although spruce forest covers most of the catchments of all brooks, none of them is typical brown water. The geology of catchments of the studied brooks, with the exception of Voldušský brook and Kotelský brook, is similar to the general characteristics of the Brdy Mts. Intercalations of shales and larger areas of basalt must be emphasised in the case of Voldušský brook and Kotelský brook, respectively. The sampling site at Červený brook is situated below a small fishpond, and, consequently, some liming effect may occur since the upper part of the catchment is strongly acidified (Stuchlík unpubl. data). Occasional liming is performed in the catchment of Litavka brook due to water quality concerns in a drinking water reservoir closely downstream the sampling site (Kulina 2000). The lowest discharge during the sampling time was registered at Smolivecký brook, which is of special character, since its catchment was altered by forest-drainage measures.

Sampling and analytical methods

The investigation was carried out on 13th December 1997. Water samples were taken prior to invertebrate ones. All analyses were conducted in the analytical laboratory of the Hydrobiological station “Velký Pálenec” near Blatná (Faculty of Science, Charles University). Conductivity was measured by conductometer CDM (Radiometer, France), pH was recorded at the beginning of determination of alkalinity by Gran titration on the automatic titrator TIM 900 (Radiometer, France), and the concentration of major ions was analysed by ion chromatography (Thermo Separation Products, USA). The laboratory participates in regular international intercalibration runs organised by NIVA, Oslo, Norway and the AQUACON project by CNR-ISE, Verbania-Pallanza, Italy. Precipitation chemistry was based on data from the Nepomuk precipitation station operated by the Institute for Forest Ecosystems Research (IFER) and published in the Tabular Survey by the Czech Hydrometeorological Institute (Fiala et al. 1999).

Benthic macroinvertebrates were collected by kick sampling (net mesh size 0.5 mm) for 5 minutes per site from riffles with stony or stony-gravelly substratum within a 10-m stretch, and preserved in 80 % alcohol. Invertebrates were identified to species or generic level, if possible, according to keys by Hrabě (1979), Rozkošný (1980), Wiederholm (1983), Losos (1996), Reusch & Oosterbroek (1997), Thomas (1997), Waringer & Graf (1997), Krno (1998), Zahrádková & Soldán (1998), Bitušík (2000) and Knoz (2001).

Tab. 1. Sampling site description, water chemistry of studied brooks at the sampling sites (the left part of the table, 13th December 1997) and precipitation chemistry from the Nepomuk precipitation station (annual weighted mean 1997/98, Fiala et al. 1999)

Brook Code		Category III			Category II			Category I			Nepomuk bulk	throughfall
		Reserva RES	Třítubecký TRI	Litavka LIT	Smolivecký SMO	Kotelský KOT	Mourový MOU	Červený CER	Voldušký VOL	wet only		
Altitude	m a. s. l.	610	570	650	685	665	510	470	480		860	
Latitude	N	49°42' 27"	49°41' 53"	49°39' 50"	49°34' 24"	49°35' 41"	49°45' 00"	49°46' 53"	49°48' 40"		49° 39' 33"	
Longitude	E	13°49' 13"	13°48' 30"	13°53' 17"	13°45' 45"	13°46' 22"	13°50' 00"	13°53' 11"	13°39' 56"		13° 49' 09"	
River basin		Klabava	Klabava	Litavka	Lomnice	Skalice	Litavka	Litavka	Klabava			
Max. width	m	3	3	2	1	1	2	3	2			
Dist. from source	km	4.3	5.6	2.1	1.5	0.5	4.7	7.5	1.7			
Precipitation	mm y ⁻¹									762	752	595
K ₂₀	µS cm ⁻¹	107.3	83.8	83.7	78.8	79.9	64.8	68.9	165.6	19.2	18.6	67.2
pH		3.9	4.2	4.3	4.4	4.9	5.3	6.6	6.7	4.6	4.6	4.1
Alk	µeq l ⁻¹	-130.6	-70.5	-54.0	-41.4	-6.2	7.1	120.3	203.7	-	-	-
NH ₄ ⁻ -N	µg l ⁻¹	0	0	0	0	0	0	0	0	397	498	576
Ca ²⁺	mg l ⁻¹	4.28	3.27	3.68	4.12	5.82	5.78	6.11	15.67	0.13	0.21	1.02
Mg ²⁺	mg l ⁻¹	1.20	1.42	1.97	2.62	3.38	2.14	2.84	12.69	0.02	0.04	0.18
Na ⁺	mg l ⁻¹	1.06	1.15	1.69	2.06	2.17	1.47	1.99	3.38	0.13	0.20	0.60
K ⁺	mg l ⁻¹	1.08	1.17	1.41	1.72	1.39	1.20	1.05	1.50	0.05	0.16	2.76
F ⁻	µg l ⁻¹	125	121	112	140	145	128	162	112	20	20	50
Cl ⁻	mg l ⁻¹	1.88	2.20	1.52	2.07	2.14	1.86	2.45	2.56	0.23	0.35	1.44
NO ₂ ⁻ -N	µg l ⁻¹	6	2	2	6	4	7	2	1	0	0	0
NO ₃ ⁻ -N	µg l ⁻¹	997	843	242	445	452	836	388	432	431	452	876
SO ₄ ²⁻	mg l ⁻¹	20.90	23.12	20.18	23.90	22.10	24.68	22.43	17.58	1.60	1.87	8.15

Tab. 2. Total (N) and relative (%) abundance of organisms of 8 sampling sites in the Brdy Mts found on 13th December 1997. ¹⁾ *Nemoura cf. cambrica* (Stephens, 1836); ²⁾ *Nemoura cf. uncinata* Despax, 1934

	RES		TRI		LIT		SMO		KOT		MOU		CER		VOL		
	Reserva	N %	Třítubecký	N %	Litavka	N %	Smolivecký	N %	Kotelský	N %	Mourový	N %	Červený	N %	Voldušký	N %	
OLIGOCHAETA																	
<i>Bythonomus lemami</i> (Grube, 1879)						1	0.4			1	0.4						
<i>Lumbriculus</i> sp.	1	1.5															
<i>Stygodrilus</i> sp.	1	1.5					4	13.8	1	0.4							
Lumbriculidae gen. sp.	2	3.0															
Naididae gen. sp.	1	1.5								1	0.4						
<i>Eiseniella tetraedra</i> (Savigny, 1826)										1	0.4						
Oligochaeta gen. sp.			2	4.5													
EPHEMEROPTERA																	
<i>Baetis rhodani</i> Pictet, 1845										1	0.4	2	0.7	1	0.2	1	0.3

<i>Ecdyonurus torrentis</i> Kimmins, 1942						1	0.4			1	0.2	4	1.2	
<i>Rhithrogena iridina</i> (Kolenati, 1859)						1	0.4							
<i>Leptophlebia vespertina</i> (Linnaeus, 1758)						2	0.8	1	0.3			5	1.5	
<i>Paraleptophlebia submarginata</i> (Stephens, 1835)										3	0.7			
PLECOPTERA														
<i>Amphinemura borealis</i> (Morton, 1894)						20	7.8	22	7.4					
<i>Amphinemura</i> sp. juv.			1	2.3	2	0.7				2	0.4			
<i>Nemoura avicularis</i> Morton, 1894						2	0.8			8	1.8	21	6.2	
<i>Nemoura cambrica</i> (Stephens, 1836)	6	9.1										5	1.5	
<i>Nemoura flexuosa</i> Aubert, 1949										1	0.2			
<i>Nemoura</i> spp.	¹⁾ 3	4.5	²⁾ 3	6.8	²⁾ 12	34.3	6	²⁾ 3	1.0	²⁾ 60	13.3	¹⁾ 25	7.3	
<i>Nemurella pictetii</i> Klapálek, 1900	1	1.5			3	1.1	4	13.8		3	0.7			
<i>Protonemura auberti</i> Illies, 1954	13	19.7	25	56.8	77	27.3			16	5.4				
<i>Protonemura meyeri</i> (Pictet, 1841)							48	18.6	20	5.4				
<i>Protonemura</i> sp. juv.											1	0.2		
<i>Leuctra hippopus</i> Kempny, 1899					1	0.4			16	6.2	17	5.7	37	8.2
<i>Leuctra nigra</i> (Olivier, 1811)	3	4.5	5	11.4	23	8.2	4	13.8	8	3.1	23	7.8	65	14.4
<i>Leuctra prima</i> Kempny, 1899											2	0.4		
<i>Leuctra rauscheri</i> Aubert, 1957									12	4.7	30	10.1		
<i>Diura bicaudata</i> (Linnaeus, 1758)	6	9.1	1	2.3	1	0.4								
<i>Siphonoperla torrentium</i> (Pictet, 1841)							1	0.4						
ODONATA														
<i>Cordulegaster annulatus</i> (Latreille, 1805)													1	0.3
MEGALOPTERA														
<i>Sialis fuliginosa</i> Pictet, 1836	2	3.0					1	0.4			1	0.2	1	0.3
TRICHOPTERA														
<i>Rhyacophila tristis</i> Pictet, 1834	3	4.5												
<i>Rhyacophila vulgaris</i> Pictet, 1834 species group			2	4.5	1	0.4			2	0.7	1	0.2	1	0.3
<i>Plectrocnemia conspersa</i> (Curtis, 1834)	9	13.6			9	3.2	1	3.4	4	1.6	5	1.7	1	0.2
<i>Hydropsyche saxonica</i> McLachlan, 1884											1	0.2	10	2.9
<i>Hydropsyche</i> sp. juv.									4	1.6			3	0.7
<i>Drusus annulatus</i> (Stephens, 1837)	5	7.6	2	4.5										
<i>Potamophylax</i> sp.													4	1.2
Limnephilidae gen. sp. juv.	1	1.5			2	0.7			1	0.4		1	0.2	
<i>Sericostoma</i> sp.									2	0.8				
<i>Odontocerum albicorne</i> (Scopoli, 1763)													1	0.3
DIPTERA – excl. Chironomidae														
<i>Dicranota</i> spp.	2	3.0	2	4.5	3	1.1			2	0.8	7	2.4	1	0.2
<i>Pedicia</i> (P.) cf. <i>rivosa</i> (Linnaeus, 1758)					3	1.1	1	3.4						

Tab. 2. continuation

	RES		TRI		LIT		SMO		KOT		MOU		CER		VOL	
	Reserva N	%	Třítubecký N	%	Litavka N	%	Smolivecký N	%	Kotelský N	%	Mourový N	%	Červený N	%	Voldušský N	%
<i>Tipula</i> sp.															3	0.9
<i>Bezzia</i> sp.									2	0.8						
<i>Prosimulium</i> sp.									1	0.4						
<i>Simulium</i> (<i>Nevermannia</i>) spp.	1	1.5			4	1.4					6	2.0	9	2.0	3	0.9
<i>Simulium</i> (<i>S.</i>) spp.					8	2.8			2	0.8	10	3.4	10	2.2		
<i>Ibisia marginata</i> (Fabricius, 1781)											6	2.0	5	1.1		
<i>Wiedemannia</i> sp.	1	1.5											1	0.2		
DIPTERA – Chironomidae																
<i>Apsectrotanypus trifascipennis</i> (Zetterstedt, 1838)					1	0.4										
<i>Conchapelopia</i> sp.									12	4.7			2	0.4	3	0.9
<i>Macropelopia</i> sp.					1	0.4	7	24.1								
<i>Trissopelopia</i> sp.													2	0.4	1	0.3
<i>Brillia modesta</i> (Meigen, 1830)					10	3.5			4	1.6	3	1.0	26	5.8	9	2.6
<i>Heterotrissocladius marcidus</i> (Walker, 1856)							5	17.2								
<i>Limnophyes</i> sp.	1	1.5														
<i>Rheocricotopus fuscipes</i> (Kieffer, 1909)															1	0.3
<i>Symposiocladius lignicola</i> (Kieffer, 1915)					1	0.4										
<i>Tokunagaia</i> cf. <i>rectangularis</i> (Goetghebuer, 1940)					1	0.4										
<i>Tvetenia calvescens</i> (Edwards, 1929)									3	1.2						
<i>Tvetenia discoloripes</i> (Goetghebuer, 1936)									1	0.4					1	0.3
Orthoclaadiinae gen. sp.									1	0.4			18	4.0		
<i>Micropsectra</i> spp.	3	4.5			3	1.1	1	3.4	84	32.6	122	41.2	186	41.2	144	42.2
<i>Polypedilum laetum</i> (Maigen, 1818) species group					1	0.4										
<i>Polypedilum scalaenum</i> (Schränk, 1803) species group															1	0.3
<i>Tanytarsus</i> sp.					1	0.4	2	6.9								
COLEOPTERA																
<i>Agabus</i> sp. (larva)					1	0.4										
<i>Deronectes platynotus</i> (Germar, 1834) (imago)			1	2.3												
<i>Helophorus</i> sp. (larva)	1	1.5														
<i>Helodes</i> spp. (larvae)					1	0.4					1	0.3			5	1.5
<i>Elmis</i> spp. (larvae)									17	6.6						
<i>Limnius</i> sp. (larva)									1	0.4						
Tot. ind. (N)	66		44		282		29		258		296		452		341	

Biological classification of the sites was based on the calculation of Jaccard's index (Ludwig & Reynolds 1988). Then, the Ward's method of linkage was used to construct a dendrogram. Statistical analyses were performed using STATISTICA software (StatSoft, Inc., USA).

RESULTS

Water chemistry

All studied sites represented poorly buffered soft water brooks very sensitive to acid atmospheric deposition, with ion compositions dominated by sulphate, calcium and magnesium (Tab. 1). The brooks were divided into three distinct categories according to their water chemistry (mainly pH, alkalinity, and calcium and magnesium concentrations) as follows: Category I was defined as $\text{pH} > 5.8$ (mean Gran alkalinity of $162 \mu\text{eq l}^{-1}$, and mean concentration of Ca^{2+} and Mg^{2+} of 10.8 and 5.33 mg l^{-1} , respectively). Category II was defined as $\text{pH} 4.8\text{--}5.8$ (mean alkalinity of $0 \mu\text{eq l}^{-1}$, mean concentration of Ca^{2+} and Mg^{2+} of 5.80 and 2.86 mg l^{-1} , respectively). Category III was defined as $\text{pH} < 4.8$ (mean alkalinity of $-74 \mu\text{eq l}^{-1}$, mean concentrations of Ca^{2+} and Mg^{2+} of 3.84 and 1.80 mg l^{-1} , respectively). The concentration of sodium varied from 1.06 to 3.38 mg l^{-1} , exhibiting a similar relationship to pH as does calcium and magnesium. Nitrates did not show any significant correlation with pH varying widely between 242 and $997 \mu\text{g N l}^{-1}$. Concentrations of potassium, fluoride, chloride and sulphate were almost identical at all the sites studied, averaging of 1.32 , 0.13 , 2.08 and 21.86 mg l^{-1} , respectively.

Data on chemistry and amount of precipitation (wet only, bulk, and throughfall) at the Nepomuk precipitation station, situated in the central part of the Brdy Mts (Fig. 1), are summarised in Tab. 1. The ionic pool was dominated by sulphate, nitrate, ammonia and hydrogen in all types of samples. Ionic concentrations were similar in wet only and bulk samples, and substantially lower than the throughfall values. This difference was more significant for sulphate (4.85 and $1.22 \text{ mg m}^{-2} \text{ yr}^{-1}$ for throughfall and bulk deposition, respectively) than for dissolved inorganic nitrogen (DIN = ammonia- plus nitrate-nitrogen; 0.86 vs. $0.63 \text{ mg m}^{-2} \text{ yr}^{-1}$). The throughfall deposition was more relevant for the totally forested catchments of all investigated brooks.

Macroinvertebrates

Altogether 73 macroinvertebrate taxa were identified in the studied brooks in the Brdy Mts (Tab. 2). The number of taxa (S) at particular sites (Tab. 3) showed a positive pH dependence. While 25–28 and 18–32 taxa were found in categories I and II, respectively, from 9–25 (mean of 16) taxa were present in the sites of category III. The Shannon-Weaver index (H') did not reveal any dependence on pH value in the investigated brooks (Fig. 2).

Oligochaeta were found at sites with pH below 5.0, whereas Ephemeroptera (mainly *Baetis rhodani*, *Ecdyonurus torrentis* and *Leptophlebia vespertina*) only at sites of categories I and II (Fig. 3). Larvae of stoneflies (Plecoptera) were abundant at all sites and the most abundant in Třítubecký, Litavka and Reserva brooks. This order was dominated by larvae of families Nemouridae (*Nemoura avicularis*, *N. cambrica*, *Protonemura auberti*, *P. meyeri* and *Amphinemura borealis*) and Leuctridae (*Leuctra nigra* and *L. hippopus*). *Diura bicaudata* (Perlodidae) occurred in brooks of category III only. One specimen of Odonata (*Cordulegaster annulatus*) was found at the site on Voldušský brook. The order Megaloptera occurred at low densities at four sites, independent of pH. Trichoptera larvae formed 30 % of the total fauna of Reserva brook and 10 % of Třítubecký brook, but were less abundant elsewhere (Fig. 3). *Plectrocnemia conspersa* was present at nearly all sites (except for Třítubecký brook), while *Drusus annulatus* was found at sites of category III and Rhyacophilidae (*Rhyacophila vulgaris* group and *R. tristis*) occurred irrespective of pH. Larvae of Diptera dominated all sites of categories I and II and in Smolivecký brook. Larvae of *Brillia modesta* and *Micropsectra* spp. (Chironomidae) occurred independent of acidity at nearly all sites, as did larvae of Simuliidae and Limoniidae (*Dicranota* sp.), representing

other groups of the order Diptera. Records of *Symposiocladius lignicola*, *Rheocricotopus fuscipes*, *Tvetenia discoloripes* and *T. calvescens* are published from Bohemia for the first time. Considerable density of Coleoptera was found at Kotelský brook only (see Tab. 2)

The dendrogram of site dissimilarities (Fig. 4) shows two distinct groups – the first one consists of the four sites of category III (Litavka, Smolivecký, Třítrubecký and Reserva brooks) and the second one of the remaining sites that cannot be further distinguished.

DISCUSSION

The low pH and high concentrations of sulphate and DIN in all types of precipitation suggest the atmospheric deposition to be the major source of acidity in the brooks studied. The observed extremely low ($<0 \mu\text{eq l}^{-1}$) values of Gran alkalinity and low concentrations of calcium and magnesium in the brooks of categories II and III are characteristics for the areas with limited alkalinity sources (low weathering and depleted base saturation of soils), exposed to the elevated acid deposition (e. g., Psenner & Catalan 1994). Such waters are usually rich in concentrations of ionic aluminium, which is potentially toxic for aquatic organisms (e. g., Driscoll & Postek 1995).

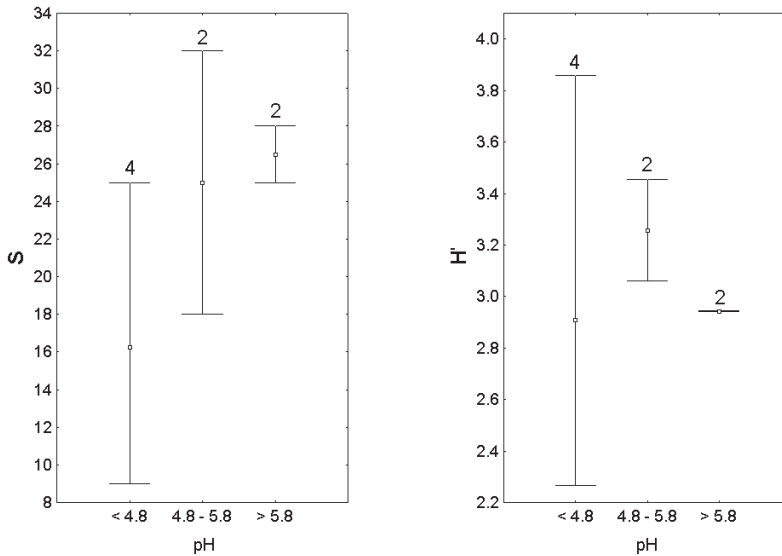


Fig. 2. Taxa richness and diversity within the three groups of brooks of different acidity (means and ranges with number of samples). S – total number of taxa, H' – Shannon-Weaver index.

Tab. 3. Number of taxa per taxonomic group from Tab. 2

	RES Reserva	TRI Třítrubecký	LIT Litavka	SMO Smolivecký	KOT Kotelský	MOU Mourový	CER Červený	VOL Voldušský
Oligochaeta	4	1	1	1	4	–	–	–
Ephemeroptera	–	–	–	–	4	2	3	3
Plecoptera	6	5	7	2	7	7	9	5
Odonata	–	–	–	–	–	–	–	1
Megaloptera	1	–	–	–	1	–	1	1
Trichoptera	4	2	3	1	4	2	5	4
Diptera	5	1	12	5	10	6	10	10
Coleoptera	1	1	2	–	2	1	–	1
Suma	21	10	25	9	32	18	28	25

Even though aluminium was not analysed in this survey, our later detailed study on Litavka brook chemistry confirmed the presence of high concentrations of reactive aluminium (up to 2000 $\mu\text{g l}^{-1}$; Kulina 2000, Stuchlík et al. 2000). Labile aluminium, most toxic to water organisms, constituted up to 70 % of that aluminium pool. This high ratio of labile to reactive aluminium in the category

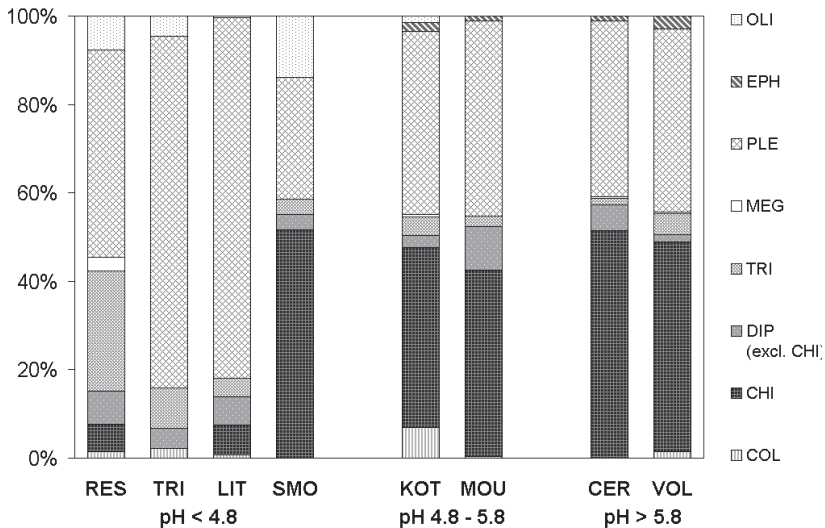


Fig. 3. Relative numbers of macroinvertebrate taxonomical groups (%; OLI–Oligochaeta, EPH–Ephemeroptera, PLE–Plecoptera, MEG–Megaloptera, TRI–Trichoptera, DIP–Diptera excluding Chironomidae, CHI–Chironomidae, COL–Coleoptera). Site abbreviations as in Tab. 1.

III brooks clearly indicates that DOC concentrations are not high enough to ameliorate significantly the toxic effects of aluminium on macroinvertebrates (Fott 1994).

Atmospheric input of sulphate and DIN in the Brdy Mts is within a typical range published for the other forest regions in the Czech Republic (Fiala et al. 1999). The observed sulphate concentrations in the brooks studied are substantially higher than could be expected from just an evapotranspiration effect, suggesting some additional sulphate sources in their catchments. Such a situation is typical for the ecosystems recovering from acidification and is associated with a wash-out of sulphate accumulated in soils during previous decades of its elevated deposition (Alewell 2000, Prechtel et al. 2001). This washing out may last several decades, as predicted for the geographically adjacent mountain areas (Kopáček et al. 2001, Hruška et al. in press). In contrast to sulphate, nitrate concentrations in the brooks are low, indicating that the forest ecosystem of the Brdy Mts is probably in the early stage of nitrogen saturation according to Stoddard (1994). The elevated export of aluminium from a catchment usually accompanies leaching of strong acid anions from the acidified soils. Due to the dominant role of sulphate in the total pool of strong acid anions in the brooks studied, the future extent of aluminium concentrations, as well as the associated toxicity will predominantly reflect the fate of sulphur accumulated in soils. Consequently, the elevated aluminium concentrations can be expected in the brooks also for the next several decades despite a >80 % decrease in sulphate emission in the Central Europe (Kopáček et al. in press).

Comparable values of conservative ions (e.g., sulphate and chloride) in the brooks (Tab. 1) suggest that even the limited data based on a single synoptic survey can provide a reasonable basis for classification of the water acidity status.

The highest total abundance of water macroinvertebrates was recorded in all streams of categories I and II and also in Litavka brook. The low numbers of individuals in Reserva and Třítrubecký brooks may be explained not only by the effects associated with acidification, but also by other environmental factors, as the influence of acidification on aquatic macroinvertebrate abundance has not been explicitly proven (Herrmann et al. 1993). Mulholland et al. (1992) consider the densities of shredder and collector-gather macroinvertebrates to be correlated rather to benthic organic matter than to pH. In the case of Smolivecký brook, the total abundance might also be poor due to its drainage ditch character. Most of the collected organisms were insects, of which Plecoptera and Diptera were the most abundant. A comparison of the composition of macroinvertebrate communities of the streams studied in the Brdy Mts shows that number of invertebrate taxa is reduced as a consequence of acidification. A decrease in species richness and diversity, and changes of composition of functional feeding groups in acidified streams, are well documented effects of acidification (e.g., Økland & Økland 1986, Szczęsny 1990, Guerold et al. 1993, Herrmann et al. 1993, Dangles & Guerold 2000). This feature results from the disappearance of Ephemeroptera, Mollusca and Crustacea, and reduced richness of other groups (Diptera, Trichoptera, Coleoptera, Plecoptera, see e. g., Raddum & Fjellheim 1984, Weatherley et al. 1989, Guerold et al. 1995, Szczęsny 1998).

Differences in tolerance to acid waters can be found within stonefly (Plecoptera) larvae, among which *Siphonoperla torrentium* is considered to be moderately sensitive (Braukmann 1994), as is *Diura bicaudata* (occurrence at pH > 5 according to Fjellheim & Raddum 1990). Other authors (Braukmann 1994, Soldán et al. 1998), however, consider the latter species as acid-tolerant. This species was already reported from the Brdy Mts by Křelinová (1962) and Pivnička et al. (1993), and found ourselves in 1997 in the most acid brooks: Reserva, Třítrubecký and Litavka. *Leuctra hippopus* and *Nemoura avicularis* appeared to be associated with waters of pH above 4.8 in the study area, although they could be expected at lower pH values as well (Fjellheim & Raddum 1990); Scheibová & Helešic (1999) found *N. avicularis* at a minimum pH of 5.5. *Amphinemura borealis*, *Nemurella pictetii*, *Leuctra nigra* and *L. rauscheri* belong to the extremely acid-tolerant stone-

flies (Fjellheim & Raddum 1990, Braukmann 1994), which is in agreement with our results. The occurrence of *Amphinemura borealis* and *Diura bicaudata*, vulnerable and endangered species in the Czech Republic (Soldán et al. 1998), deserve attention from the faunistic point of view.

Heterotrissocladius marcidus, an acid-tolerant chironomid species (Orendt 1999), occurred at relatively high abundance in acid Smolivecký brook. The presence of *Apsectrotanypus trifasciipennis* larva in Litavka brook (pH 4.3) is in contradiction with its extreme acid-sensitivity supposed by Orendt (1999), though in this case it can be associated with an imbalance of the acidity state as a consequence of liming. The increase of *Micropsectra* spp. abundance with increasing pH in investigated streams might reflect its moderate sensitivity to acid conditions. The record of *Symposiocladius lignicola* is interesting from the faunistic point of view; this species, so far known from Moravia and Slovakia (Bitušik & Losos 1997), is reported from Bohemia for the first time. Due to specific morphological features of its larva, this species is easily distinguishable from other species of the subfamily Orthoclaadiinae (Bitušik 2000). The occurrence of larvae of the *Poly-pedilum* (*Tripodura*) *scalaenum* group in Bohemia was shown only recently (Chalupová & Matěna 2002). Other species recorded not listed in Bitušik & Losos (1997), namely *Rheocricotopus fuscipes*, *Tvetenia discoloripes* and *T. calvescens*, occur in the Czech Republic frequently (Matěna, pers. comm.).

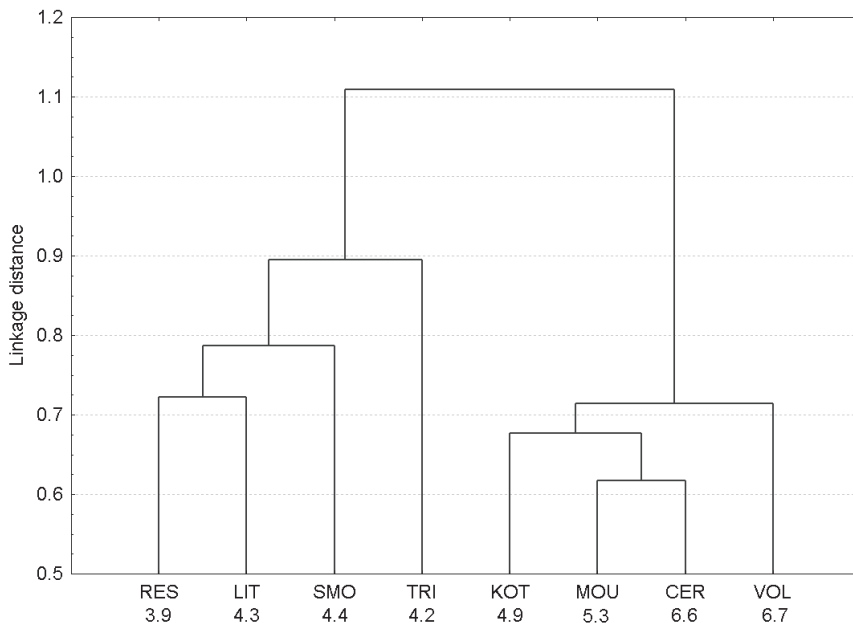


Fig. 4. Biological classification of sites based on Jaccard's index of similarity; recorded water pH is indicated below. Site abbreviations as in Tab. 1.

Rhyacophila larvae (Trichoptera) are generally regarded as acid-tolerant, with the exception of *R. tristis* which is considered more sensitive (Guerold et al. 1993, 1995, Braukmann 1994), preferring waters with pH 5.4–7.4 (Novák 1962). Surprisingly, *R. tristis* was found in Reserva brook at pH 3.9. *Plectrocnemia conpersa* exhibits a great tolerance to acidification as has been well documented earlier (e. g., Fjellheim & Raddum 1990, Scheibová & Helešic 1999). This most abundant caddisfly species of streams in the Brdy Mts occurs independent of acidity. *Drusus annulatus* was recorded only in streams of category III; larvae of this common mountain species of the Czech Republic also inhabit streams with low pH in other acidified regions (Horecký unpubl. data). This species was reported as acid-tolerant e. g. from the Vosges Mts (Guerold et al. 1995), although Szczęsny (1990, 1998) did not find it in acidified streams of the West Carpathians.

The majority of Ephemeroptera species are strongly acid-sensitive and therefore become extinct in waters below pH 5–5.5 (Økland & Økland 1986, Herrmann et al. 1993, Havas & Rosseland 1995). In the investigated streams, mayflies were recorded at sites with pH > 4.8. *Baetis rhodani*, considered a potential indicator species of non-acidified waters (Larsen et al. 1996) and extremely acid-sensitive (e.g. Scheibová & Helešic 1999), was found at pH around 5 in the Brdy Mts, which better correspond to Engblom & Lingdell (1984), who mention this species as moderately acid-tolerant showing somewhat lower pH tolerance limits (4.5). On the other hand, we recorded *Lep-tophlebia vespertina* only in streams of categories I and II although this species is known as extremely acid-tolerant (Larsen et al. 1996) and Engblom & Lingdell (1984) report survival of this species up to pH 3.5. Its absence at sites with the lowest pH might be the consequence of unfavourable flow conditions there, since *L. vespertina* larvae prefer habitats with low current speed or pools (Soldán et al. 1998).

The permanent fauna is represented only by Oligochaeta found in streams with pH < 5. Since Oligochaeta belong to acid-tolerant organisms often forming the major component of the bottom fauna under acidic conditions (Weatherley et al. 1989, Guerold et al. 1995), their absence or low abundance can reflect the absence of fine sediments at the sampled sites or the sampling procedure. Aquatic Mollusca and Crustacea, generally considered acid-sensitive (e. g., Økland & Økland 1986), were not found at the studied sites, but occur in more alkaline waters of the Brdy Mts (Roubal & Štorkán 1924, Pivnička et al. 1993, Horecký unpubl. data).

The biological classification corresponds well with characteristics based on water chemistry data distinguishing the group of streams highly impacted by atmospheric deposition (category III). Although point liming at the Litavka catchment results in episodic extremes of water pH up to neutral or alkaline values, the site still appears to be unfavourable for mayflies, either due to pH imbalance (Kulina 2000, Stuchlík et al. 2000) or low minimum pH. On the other hand, relatively low differences in species composition of the remaining sites (categories I and II) probably represent a consequence of episodic acidification. Our results confirm the importance of biological assays, especially in the case of non-frequent water sampling.

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REFERENCES

- ALEWELL C., MANDERSCHIED B., MEESENBURG H. & BITTERSÖHL J. 2000: Is acidification still an ecological threat? *Nature* **407**: 856–857.

- BITUŠÍK P. & LOSOS B. 1997: *Chironomidae*. Pp.: 34–39. In: CHVÁLA M. (ed.): *Check list of Diptera (Insecta) of the Czech and Slovak Republics*. Praha: Karolinum – Charles University Press, 130 pp.
- BITUŠÍK P. 2000: *Príručka na určovanie lariev pakomárov (Diptera: Chironomidae) Slovenska – časť I. – Buchonomyiinae, Diamesinae, Prodiamesinae a Orthocladiinae [A handbook to identification of chironomid larvae (Diptera: Chironomidae) of Slovakia – part. I – Buchonomyiinae, Diamesinae, Prodiamesinae a Orthocladiinae]*. Zvolen: Technická univerzita vo Zvolene, 133 pp (in Slovak).
- BRAUKMANN U. 1994: *Bioindikation Des Säurezustands von Fließgewässern auf der Grundlage des Makrozoobenthos – Beschreibung des Verfahrens – Interner Bericht, Stand 1.6.1994*. Karlsruhe: Landesamt für Umweltschutz Baden-Württemberg, 11 pp.
- DANGLES O. J. & GUEROLD F. A. 2000: Structural and functional responses of benthic macroinvertebrates to acid precipitation in two forested headwater streams (Vosges Mountains, northeastern France). *Hydrobiologia* **418**: 25–31.
- DRISCOLL, C. T., & K. M. POSTEK. 1995: The chemistry of aluminum in surface waters. Pp.: 363–418. In: SPOSITO G. (ed.): *The environmental chemistry of aluminum*. Chelsea: Lewis Publishers, 464 pp.
- ENGBLOM E. & LINGDELL P. E. 1984: The mapping of short-term acidification with the help of biological pH indicators. *Rep. Inst. Freshw. Res., Drottningholm* **61**: 60–68.
- FIALA J., SLÁDEČEK J., DVORÁKOVÁ M., HÜNOVÁ I., NOVÁK V., OSTATNICKÁ J., BUBNÍK J., BARTÁČKOVÁ Z. & PROKŮPKOVÁ L. 1999: *Air pollution and atmospheric deposition in data, the Czech Republic 1998*. Praha: ČHMÚ, 296 pp.
- FJELLHEIM A. & RADDUM G. G. 1990: Acid precipitation: Biological monitoring of streams and lakes. *Sci. Total. Environ.* **96**: 57–66.
- FOTT J., PRAŽÁKOVÁ M., STUHLÍK E. & STUHLÍKOVÁ Z. 1994: Acidification of lakes in Šumava (Bohemia) and in the High Tatra Mountains (Slovakia). *Hydrobiologia* **274**: 37–47.
- GUEROLD F., VEIN D., JACQUEMIN G. & MORETEAU J. C. 1993: Impact de l'acidification des ruisseaux vosgiens sur la biodiversité de la macrofaune benthique. *C. R. Acad. Sci. Paris, Sci. Vie, Écol.* **316**: 1388–1392.
- GUEROLD F., VEIN D., JACQUEMIN G. & PIHAN J. C. 1995: The macroinvertebrate communities of streams draining a small granitic catchment exposed to acidic precipitations (Vosges Mountains, north-eastern France). *Hydrobiologia* **300/301**: 141–148.
- HALL R. J. & IDE F. P. 1987: Evidence of acidification effects on stream insects communities in central Ohio between 1937 and 1985. *Can. J. Fish. Aquat. Sci.* **44**: 1652–1657.
- HAVAS M. & ROSSELAND B.O. 1995: Response of zooplankton, benthos, and fish to acidification: An overview. *Water Air Soil Pollut.* **85**: 51–62.
- HAVLIČEK V. 1986: *Geologická mapa ČSR 1 : 50 000. List 12 – 34 Hořovice [Geological map of the Czech Socialist Republic 1 : 50 000. 12–34 Hořovice]*. Praha: ÚÚG Praha.
- HERRMANN J., DEGERMAN E., GERHARDT A., JOHANSSON K., LINGDELL P. & MUNIZ I. P. 1993: Acid-stress Effects on Stream Biology. *Ambio* **22**: 298–307.
- HRABĚ S. 1979: The freshwater Oligochaeta (Annelida) of Czechoslovakia. *Acta Univ. Carol. – Biol.* **1976**: 1–167 (in Czech, Engl. abstr.).
- HRUŠKA J., MOLDÁN F. & KRÁM P. 2002: Recovery from acidification in Central Europe – observed and predicted changes of soil and streamwater chemistry in the Lysina catchment, Czech Republic. *Environ. Pollut.* [Accepted 25 January 2002].
- CHALUPOVÁ Š. & MATĚNA J. 2002: Chironomid communities of the Upper Stropnice River (Novohradské Mountains, (South Bohemia). Pp.: 245–250. In PAPAČEK M. (ed.): *Biodiverzita a přírodní podmínky Novohradských hor [Biodiversity and environmental factors of the Novohradské Mts]*. České Budějovice: Jihočeská univerzita v Českých Budějovicích a Entomologický ústav AV ČR, 285 pp (in Czech, Engl. abstr.).
- KNOZ J. 2001: *Determinační kurz makrozoobentosu – Diptera – Simuliidae a Ceratopogonidae [An identification course of macroinvertebrates – Diptera – Simuliidae and Ceratopogonidae]*. Brno: VÚV Praha a Masarykova univerzita v Brně, 35 pp (in Czech).
- KOPÁČEK J., STUHLÍK E., ŠTRAŠKRABOVÁ V. & PŠENÁKOVÁ P. 2000: Factors governing nutrient status of mountain lakes in the Tatra Mountains. *Freshwater Biol.* **43**: 369–383.
- KOPÁČEK J., VESELÝ J. & STUHLÍK E. 2001: Sulphur and nitrogen fluxes and budgets in the Bohemian Forest and Tatra Mountains during the Industrial Revolution (1850–2000). *Hydrology and Earth Sci.* **5**: 391–405.
- KOPÁČEK J., STUHLÍK E., VESELÝ J., SCHAUMBURG J., ANDERSON I. C., FOTT J., HEJZLAR J. & VRBA J. 2002: Hysteresis in reversal of Central European mountain lakes from atmospheric acidification. *Water Air Soil Pollut*, in press.
- KRÁM P. & HRUŠKA J. 1994: Influence of bedrock geology on elemental fluxes in two forested catchments affected by high acidic deposition. *Appl. Hydrogeol.* **2**: 50–58.

- KRNO I. 1998: Pošvatky (Plecoptera) Slovenska [Stoneflies (Plecoptera) of Slovakia]. Pp.: 34–62. In: MAKOVINSKÁ J., TÓTHOVÁ L., ELEXOVÁ E. & ŽIVIČOVÁ Z. (eds.): *Zborník z hydrobiologického kurzu '98*. Bratislava: VÚVH v Bratislavě, 78 pp (in Slovak).
- KŘELINOVÁ E. 1962: *K poznání českých pošvatek (Plecoptera). Studie o bionomii a zoogeografii bentické české zvířeny [To the knowledge of the Czech stoneflies (Plecoptera). A study of bionomy and zoogeography of the Czech benthic fauna]*. Unpubl. PhD thesis. Praha: Entomologický ústav AV ČR, 265 pp (in Czech).
- KULINA J. 2000: *Vliv antropogenní acidifikace na kvalitu povrchových vod v oblasti pohorí Brdy [Influence of anthropogenic acidification on the surface water quality in the area of the Brdy Mts]*. Unpubl. Master thesis. Praha: Univerzita Karlova, 59 pp (in Czech, Engl. summary).
- LANDA V. & SOLDÁN T. 1989: *Rozšíření řádu Ephemeroptera v ČSSR s ohledem na kvalitu vody [Distribution of order Ephemeroptera in Czechoslovakia with respect to water quality]*. Praha: Academia, 172 pp (in Czech, Engl. summary).
- LARSEN J., BIRKS H. J. B., RADDUM G. G. & FJELLHEIM A. 1996: Quantitative relationships of invertebrates to pH in Norwegian river systems. *Hydrobiologia* **328**: 57–74.
- LIEN L., RADDUM G. G., FJELLHEIM A. & HENRIKSEN A. 1996: A critical limit for acid neutralizing capacity in Norwegian surface waters, based on new analyses of fish and invertebrate responses. *Sci. Total. Environ.* **177**: 173–193.
- LOSOS B. 1996: *Klíč k určování larev pakomárovitých (Chironomidae) [An identification key to chironomid larvae (Chironomidae)]*. Brno: Masarykova Univerzita Brno, 131 pp (in Czech).
- LUDWIG J. A. & REYNOLDS J. F. 1988: *Statistical ecology: a primer on methods and computing*. New York: Wiley Interscience, 337 pp.
- MAŠEK J. 1990: *Geologická mapa ČR 1 : 50 000. List 22 – 12 Břežnice [Geological map of the Czech Republic 1:50 000. 22–12 Břežnice]*. Praha: ÚÚG Praha.
- MULHOLLAND P. J., DRISCOLL C. T., ELWOOD J. W., OSGOOD M. P., PALUMBO A. V., ROSEMOND A. D., SMITH M. E. & SCHOFIELD C. 1992: Relationships between stream acidity and bacteria, macroinvertebrates, and fish: A comparison of north temperate and south temperate mountain streams, USA. *Hydrobiologia* **239**: 7–24.
- NOVÁK K. 1962: Die Verbreitung der Arten der Gattung Rhyacophila Pict. in Böhmen (Trichoptera). *Čas. Čs. Společ. Entomol.* **59**: 250–265.
- ØKLAND J. & ØKLAND K. A. 1986: The effects of acid deposition on benthic animals in lakes and streams. *Experientia* **42**: 471–486.
- ORENDT C. 1998: Macroinvertebrates and diatoms as indicators of acidification in forest spring brooks in a region of eastern Germany (Leipzig-Halle-Bitterfeld) highly impacted by industrial activities. *Arch. Hydrobiol.* **143**: 435–467.
- ORENDT C. 1999: Chironomids as bioindicators in acidified streams: a contribution to the acidity tolerance of chironomid species with a classification in sensitivity classes. *Internat. Rev. Hydrobiol.* **84**: 439–449.
- PETŘÍČEK V. & DEJMAL I. 1998: Sjednocení všech úrovní územního systému ekologické stability (ÚSES) v brdském bioregionu [An integration of the systems of ecological stability (USES) at all levels]. Pp.: 56–63. In: NĚMEC J. (ed.): *Příroda Brd a perspektivy její ochrany [The nature of the Brdy Mts and perspectives of its protection]*. Příbram: EnviTypo Praha, 129 pp (in Czech).
- PIVNÍČKA K., BENEŠOVÁ L., PIVNÍČKOVÁ M., PŘIBIL R., TONIKA J. & RŮŽIČKOVÁ J. 1993: Studium malých vodních toků v Brdech s poznámkami o významu oblasti v rámci chráněných krajinných celků [Study of small streams in Brdy Mts with notes on the area importance in range of nature protected complexes]. Pp.: 68–73. In: NĚMEC J. (ed.): *Příroda Brd a perspektivy její ochrany [The nature of the Brdy Mts and perspectives of its protection]*. Příbram: OÚ Příbram, 120 pp (in Czech).
- PRECHTEL A., ALEWELL C., ARMBRUSTER M., BITTERSÖHL J., CULLEN J., EVANS C., HELLIWELL R., KOPÁČEK J., MARCHETTO A., MATZNER E., MEESENBURG H., MOLDAN F., MORITZ K., VESELÝ J. & WRIGHT R. F. 2001: Response of sulfur dynamics in European catchments to decreasing sulfate deposition. *Hydrol. Earth System Sci.* **5**: 311–325.
- PSENNER R. & CATALAN J. 1994: Chemical composition of lakes in crystalline basins: a combination of atmospheric deposition, geologic background, biological activity and human action. Pp.: 255–314. In: MARGALEF R. (ed.): *Limnology Now: A Paradigm of Planetary Problems*. Amsterdam: Elsevier, 553 pp.
- RADDUM G. G. & FJELLHEIM A. 1984: Acidification and early warning organisms in freshwater in western Norway. *Verh. Internat. Verein. Limnol.* **22**: 1973–1980.
- REUSCH H. & OOSTERBROEK P. 1997: Diptera Limoniidae & Pediciidae. Pp.: 105–132. In: NILSSON A. (ed.): *The aquatic insects of North Europe 2*. Stenstrup: Apollo Books, 440 pp.
- ROUBAL J. & ŠTORKÁN J. 1924: [The Brdy Mts from the zoological point of view]. *Musejní Spisy Městského Musea v Rokycanech* **8**: 1–4 (in Czech).

- ROZKOŠNÝ R. (ed.) 1980: *Klíč vodních larev hmyzu [A key to aquatic insect larvae]*. Praha: Academia, 524 pp (in Czech).
- RŮŽIČKOVÁ J. 1998: Water insect community in streams of Bavarian Forest with different stages of acidification. *Silva Gabreta* **2**: 199–209 (in Czech, Engl. abstr.).
- SCHEIBOVÁ D. & HELEŠIČ J. 1999: Hydrobiological assessment of stream acidification in the Czech-Moravian highland, Czech Republic. *Scripta Fac. Sci. Natur. Univ. Masarykianae Brunensis* **25**: 13–32.
- SOLDÁN T., ZAHRÁDKOVÁ S., HELEŠIČ J., DUŠEK L. & LANDA V. 1998: Distributional and quantitative patterns of Ephemeroptera and Plecoptera in the Czech Republic: a possibility of detection of longterm environmental changes of aquatic biotopes. *Folia Fac. Sci. Natur. Univ. Masarykianae Brunensis, Biologia* **98**: 1–305.
- STODDARD J. L. 1994: Long-term changes in watershed retention of nitrogen. Pp.: 223–284. In: BAKER L. A. (ed.): *Environmental Chemistry of Lakes and Reservoirs*. Advances in Chemistry 237. Washington, D.C.: American Chemical Society, 627 pp.
- STUHLÍK E., HORECKÝ J. & KULINA J. 2000: Vliv kyselé atmosférické depozice na chemismus a oživení pramenného úseku řeky Litavky [The effects of acid atmospheric deposition on chemistry and biota of spring area of the Litavka river]. Pp.: 130–133. In: NĚMEC J. (ed.): *Modelové území povodí Litavky [Model area of Litavka river catchment]*. Příbram: 43. ZO ČSOP Praha, 136 pp (in Czech).
- STUHLÍK E., STUHLÍKOVÁ-HOŘICKÁ Z., PRCHALOVÁ M., KŘEČEK J. & BARICA J. 1997: Hydrobiological investigation of three acidified reservoirs in the Jizera Mountains, the Czech Republic, during the summer stratification. *Can. Tech. Rep. Fish. Aquat. Sci.* **2155**: 56–64.
- SZCZESNY B. 1990: Benthic macroinvertebrates in the acidified streams of the Światokrzyski National Park (central Poland). *Acta Hydrobiol.* **32**: 155–169.
- SZCZESNY B. 1998: Benthic macroinvertebrates in the acidified headstreams of the Vistula river. *Stud. Natur.* **44**: 145–170.
- THOMAS A. G. B. 1997: Diptera Rhagionidae & Athericidae, Snipe-flies. Pp.: 311–320. In: NILSSON A. (ed.): *The aquatic insects of North Europe 2*. Stenstrup: Apollo Books, 440 pp.
- VESELÝ J. & MAJER V. 1996: The effect of pH and atmospheric deposition on concentrations of trace elements in acidified freshwaters: A statistical approach. *Water Air Soil Pollut.* **88**: 227–246.
- VESELÝ J. & MAJER V. 1998: Hydrogeochemical mapping of Czech freshwaters. *Bull. Czech Geol. Survey* **73**: 183–192.
- VESELÝ J., HRUŠKA J., NORTON S. A. & JOHNSON C. E. 1998: Trends in water chemistry of acidified Bohemian lakes from 1984 to 1995: I. Major solutes. *Water Air Soil Pollut.* **108**: 107–127.
- VRBA J., KOPÁČEK J., FOTT J., NEDBALOVÁ L., KOHOUT L., SOLDÁN T., SCHAUMBURG J. 2002: Long-term (1871–2000) lake research in the Bohemian Forest (Central Europe) covering periods of atmospheric acidification and present recovery from acid stress. *Sci. Total. Environ., Spec. Issue*, in press.
- WARINGER J. & GRAF W. 1997: *Atlas der österreichischen Köcherfliegenlarven unter Einschluss der angrenzenden Gebiete*. Wien: Facultas Universitätsverlag, 286 pp.
- WEATHERLEY N. S., RUTT G. P. & ORMEROD S. J. 1989: Densities of benthic macroinvertebrates in upland Welsh streams of different acidity and land use. *Arch. Hydrobiol.* **115**: 417–431.
- WIEDERHOLM T. (ed.) 1983: Chironomidae of the Holarctic region – Keys and diagnoses – Part 1 Larvae. *Entomol. Scand. Suppl.* **19**: 1–457.
- ZAHRÁDKOVÁ S. & SOLDÁN T. 1998: *Determinační kurz makrozoobentosu – Ephemeroptera [An identification course of macroinvertebrates – Ephemeroptera]*. Brno: VÚV Praha a Masarykova univerzita v Brně, 30 pp (in Czech).