Preimaginal stages of Diptera (excluding Chironomidae and Simuliidae) of mountain lakes, their inlets and outlets in the Tatra Mountains (Slovakia)

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Abstract: The occurrence of preimaginal stages of Diptera (excluding Chironomidae and Simuliidae) in the Tatra Mountain lakes, their inlets and outlets, and the influence of acidification on the presence of these taxa were assessed. At 21 sites, 18 Diptera taxa were recorded in 2000 and 2001. The most frequent were *Dicranota* sp. (73%), *Pedicia* (*C.*)*rivosa* (50%) and *Wiedemannia* sp. (14%). Diptera were ordinated by RDA; relationships between taxa and environmental variables were significantly determined by temperature and habitat characteristics (altitude, habitat, alkalinity, Ca^{2+}, pH, temperature, conductivity). The RDA diagram confirmed the existence of four Diptera assemblage groups corresponding with four habitat types. Group 1 – alpine and subalpine oligotrophic lakes at higher altitudes threatened by acidification, with the acid tolerant taxa *Tipula rufina, T. alpium, Dicranota* sp. and *Rhypholophus* sp. Group 2 – subalpine oligotrophic lakes not threatened by acidification with the acid sensitive taxa *Wiedemannia* sp., *Hemerodromia* sp., *Tipula* (*S.*)*benesignata, Orimarga* sp.,*Chionea* sp.*, Pedicia* (*C.*)*rivosa* and *Bazarella subneglecta* which prefer higher temperature. Group 3 – subalpine oligotrophic lakes, with the acid sensitive species*Berdeniella illiesi*, which prefers cold water. Group 4 – outlets of submontane oligotrophic lakes with characteristic taxa *Tricyphona* sp. and *Tipula goriziensis*. Acidified alpine and subalpine Tatra lakes are situated mostly at higher altitudes (1705–2145 m a.s.l.) and have specific taxonomic composition.

Key words: Mountain lakes, inlet, outlet, preimaginal stages, Diptera, *Savtshenkia*, acidification, Slovakia.

Introduction

Glacial lakes in the Tatra Mountains (Mts), with their inlets and outlets creating mountain streams, are among the most unique biotopes in Slovakia. Most of them lie in the alpine and subalpine zones with extreme natural conditions, which – in conjunction with human impact – make them very vulnerable. This is why these habitats are also very attractive for researchers. The last century brought relatively good knowledge of their fauna not only from the faunistic (e.g., Minkiewicz, 1914; Hrabě, 1939; Chvojka, 1992), but also from the hydrobiological point of view, with emphasis mainly on the process of acidification (Krno et al., 1985; Krno, 1988, 1991; Stuchlík et al., 1985; Šporka, 1992; Vranovský et al., 1994). The most explored Diptera group of the Tatra lakes are the chironomids, as dominant part of the macrozoobenthic assemblages of these biotopes (Zavřel, 1935; Ertlová, 1987; Bitušík et al., 2003, 2006; Bitušík, 2004; Hamerlík, 2004). Blackflies (Simuliidae) live in the Tatra Mts in mountain streams only; their communities were studied by Illéšová et al. (2000). Data concerning other Diptera taxa from the Tatra lakes and their inlets and outlets are very scarce and restricted to a few works dealing with larvae (Krno, 1991) or adults (Martinovský, 1984). A few studies focused on Tatra alpine lake outlets have reported invertebrate assemblages to be similar to those of other alpine streams (Kownacki et al., 1997).

The material processed in this study comes from macrozoobenthic samples obtained within the scope of the multilateral and multidimensional European project EMERGE, which was a continuation of the previous projects AL: PE and MOLAR, focused on the ecology of high mountain lakes throughout Europe (for review see Štefková & Šporka, 2001). The aim of this paper was to evaluate the occurrence of preimaginal stages of Diptera (excl. Chironomidae, Simuliidae) in the Tatra lakes, including their inlets and outlets, and to assess the influence of acidification on the presence of these taxa.

Material and methods

Study area

The whole study area belongs to the Tatra Mts (specifically the High Tatra and West Tatra Mts), which are part of the West Carpathians and lie at the border between Slovakia and Poland. Eurasian continental climate affects the precipitation regime (with the highest amount of precipitation in June and July and the lowest from January to April), as well as the hydrology (streams and mountain lakes). The massif of the Tatra Mts forms the European watershed divide between the Baltic Sea and the Black Sea. The majority of the Slovak Tatra lakes belong to the Baltic Sea river basin. In the whole area of the Tatra Mts, there are approximately 130 lakes of glacial origin.

As the bedrock is formed mainly by granodiorites, the water in the majority of lakes is extremely poor in inorganic and organic compounds and has very low neutralizing capacity, a consequence of which has been the acidification (or threat of acidification) of many lakes.

Within the framework of the EMERGE project, 34 mountain lakes plus their inlets and outlets on the Slovak part of the Tatra Mts were studied. Lakes differed in geomorphological characteristics, e.g., altitude, lake area, catchment, etc. All the lakes were permanent and situated above the tree line. The vegetation in the catchments was represented only by alpine meadows and dwarf pine, so that leaf litter on the bottom was absent. This work involves only selected sites, where Diptera larvae and pupae were found: 6 inlets, 8 littorals and 7 outlets. The list of all sites and their basic characteristics are given in Table 1 (site numbers correspond with site codes of the EMERGE project.

Sampling and evaluation methods

The material of preimaginal stages of Diptera was obtained from two studies: 1. Within the scope of the EMERGE project, sampling of macrozoobenthos at all sites was done once in September 2000. One semiquantitative sample from each sampling site, using a hand-net (25 × 25 cm frame and 300 μm mesh-size) was taken. The "kicking technique" (FROST et al., 1971) was used, disturbing the substrate for 5 min. 2. Four selected lakes (Vyšné Wahlenbergovo pleso, Nižné Terianske pleso, Vyšné Temnosmrečinské pleso and Nižné Temnosmrečinské pleso) were sampled regularly in monthly intervals during the growing seasons of 2000 and 2001. A triangular "Kubíček's benthometer" (Hess type of sampler with the area of 0.1 m^{-2} and PE sieve with a mesh size 0.5 mm) for obtaining quantitative samples from littorals (depth up to 40 cm), and the hand-net and "kicking technique" in inlets and outlets (max. 10 m from the lake margin) were used.

All samples were put into plastic bottles and fixed in 4% formalin in the field. In the laboratory, the material was sorted using a stereomicroscope. Organisms were separated into higher taxonomical groups and preserved in 75% ethanol. In September 2000, basic physical and chemical parameters of 14 sites were also measured.

The collected preimaginal stages of Diptera were identified to the lowest possible level according to SAVCHENKO (1961), THEOWALD (1967), ROZKOŠNÝ (1980) and WAGNER (1983).

Redundancy analysis (RDA) included in the CANOCO 4.5 software (TER BRAAK & ŠMILAUER, 2002) was performed to analyse the relationships between species and environmental data. The input data were standardized to reduce inter-sample differences.

Results

The list of aquatic and semiaquatic Diptera taxa (excl. Chironomidae, Simuliidae) found at 21 sites in the Tatra Mts is given in Table 2. In all, 18 taxa of Diptera belonging to six families were recorded. Larvae of Ceratopogonidae were not found.

From the faunistic point of view, the occurrence of the species of genus *Tipula*, subgenus *Savtshenkia* Mannheims, 1962 is very interesting. These larvae are confined to cold water and mosses. The most frequent taxa were *Dicranota* sp. (with 73% frequency), followed by *Pedicia* (*C.*) *rivosa* (50%) and *Wiedemannia* sp. (14%). Some taxa were found exclusively in lotic conditions (inlet, outlet: *Tricyphona* sp., *Tipula* (*S.*) *goriziensis*, *Tipula* (*S.*) *subnodicornis, Liponeura c. minor, Wiedemannia* sp.), whereas others only in lenitic conditions (littoral: *Tipula* (*L.*) *alpina, Tipula* (*S.*) *rufina*). Some taxa were found in the littoral near the inlet (Tab. 2); these probably could have drifted from the inlet.

The influence of some environmental factors common for the littoral and outlets of selected lakes (altitude, habitat, alkalinity, Ca^{2+}, pH, temperature and conductivity) was evaluated (Fig. 1). Among the environmental variables, the influences of temperature ($P = 0.0258$) and habitat ($P = 0.072$) were statistically significant. The impact of alkalinity was also evaluated ($P = 0.258$); it is among the three most significant variables with conditional effects. The first two canonical axes accounted for 43.7% of variance of the species data and 95.6% of the species – environment relationships. The eigenvalues of the first two canonical axes are $\lambda_1 = 0.274$ and $\lambda_2 = 0.163$ (Tab. 3).

The RDA diagram (Fig. 1) confirmed the existence of four assemblage groups corresponding with four habitat types with different characteristics:

Group 1 contains samples from the lakes Vyšné Wahlenbergovo pleso, Veľké spišské pleso, Prostredné spišské pleso, Vyšné Žabie bielovodské pleso and Batizovské pleso. According to the typology of Tatra lakes (KRNO, 1991), most of these lakes are alpine (sites 17, 32, 54, 56) or subalpine oligotrophic lakes at higher altitude (sites 37, 41, Tab. 1). These lakes are threatened by acidification (pH 5.97–6.58) and acid tolerant taxa *Tipula rufina, T. alpium, Dicranota* sp. and *Rhypholophus* sp. are characteristic for them.

Group 2 consists of samples from Nižné Temnosmrečinské pleso – a subalpine oligotrophic lake not threatened by acidification (pH 7.21). Taxa living in this habitat type (*Wiedemannia* sp., *Hemerodromia* sp., *Tipula* (*S.*) *benesignata*, *Orimarga* sp., *Chionea* sp., *Pedicia* (*C.*) *rivosa*, *Bazarella subneglecta*) are acid sensitive and prefer higher temperature.

Table 1. Basic geomorphological and physico-chemical characteristics of selected Tatra lakes.

Parameter / Site	Štvrté Roháčske pleso	Nižné Jamnícke pleso	Vyšné Račkove pleso	Nižné Terianske pleso	Vyšné Wahlenbergovo pleso	Nižné Temnosmrečinské pleso	Vyšné Temnosmrečinské pleso	Veľké Hincovo pleso	Vyšné Žabie bielovodské pleso	Batizovské pleso	Malé žabie javorové pleso	Veľké spišské pleso	Prostredné spišské pleso	Vyšné Furkotské pleso
Site code	TA0001	TA0003	TA0004	TA0011	TA0017	TA0019	TA0022	TA0027	TA0032	TA0037	TA0041	TA0054	TA0056	TA0105
Site number	1	3	4	11	17	19	22	27	32	37	41	54	56	105
Latitude N	49.2057	49.203	49.2	49.1698	49.1642	49.1929	49.1891	49.1797	49.1942	49.1523	49.2025	49.1932	49.1914	49.1437
Longitude E	19.627	19.7717	19.8065	20.0143	20.0271	20.0306	20.0395	20.0606	20.0943	20.1315	20.1503	20.1964	20.1988	20.0314
Altitude (m a.s.l.)	1718	1728	1697	1941	2145	1674	1716	1946	1699	1879	1705	2014	2013	1698
River basin	BL	BL	BL	BL	BL	BL	BL	BA	BA	BA	BA	BA	BA	BA
Lake area (ha)	1.5	1.1	0.7	4.9	5.0	10.5	5.0	18.2	8.1	2.8	0.3	2.4	1.8	0.5
Depth (m)	8.1	9.2	12.7	43.2	21.1	40.5	20.0	53.2	24.3	11.2	4.0	9.6	5.1	3.4
Littoral description (R:S:O%)	75:15:10	80:10:10	75:15:10	90:10:0	95:4:1	80:15:5	88:8:4	90:8:2	85:13:2	90:5:5	95:5:0	80:20:0	70:25:5	90:10:0
Secchi disc depth	bottom	bottom	bottom	12	6.2	14.2	14	12	15	bottom	bottom	bottom	bottom	bottom
Habitat	I	I	I	I, O	L	L, O	I, L, O	I	L, O	O	l, O	L	L, O	L
Total catchment area (ha)	14	49	56	110	32	215	112	127	101	234	29	123	169	14
Actual temperature (℃)	9		7.6		6.2	9.8	5.8	7.8	8.5	6	5.5	6.4	7	-
pH	6.45	7.19	7.17	6.73	6.26	7.21	7.19	6.85	6.58	6.33	6.70	6.18	5.97	6.54
Ca (mg L^{-1})	1.61	3.40	2.87	2.60	1.26	4.56	4.82	2.94	1.87	1.62	2.24	1.43	1.18	1.76
Alkalinity (μeq L^{-1})	40.79	219.15	219.15	89.02	29.25	235.71	261.92	105.60	55.41	32.99	76.84	23.10	16.24	50.51
Conductivity (μS cm L^{-1} 20℃)	14.64	29.11	29.11	17.36	10.52	30.37	33.20	20.35	14.64	13.72	16.64	11.12	10.58	15.47

Key: R – rocks, S – sand, O – organic matter; BL – Black Sea, BA – Baltic Sea; I – inlet, L – littoral, O – outlet.

Table 2. The list of preimaginal stages of Diptera (excl. Chironomidae, Simuliidae) of Tatra lakes, their inlets and outlets recorded in 2000–2001, with categories of their abundance.

Taxon / Site	TA0001	TA0003	TA0004	TA0011		TA0017	TA0019		TA0022			TA0027	TA0032		TA0037	TA0041		TA0054	TA0056		TA0105	Frequency (%)
	I	I	I	I	O	L	L	O	I	L	O	I	L	O	O	L	O	L	L	O	L	
Limoniidae																						
Chionea sp.							1															5
Orimarga sp.							2*															5
Rhypholophus sp.																1						5
Pediciidae																						
Dicranota sp.	1	1	1	2	2		3*	1		1			3	1			1	3	3	1	1	73
Pedicia (P.) rivosa L., 1758	1	1	1				2*	1	1	1		1	1		1							50
Tricyphona sp.									1								1					9
Tipulidae																						
Tipula (L.) alpina Loew,1873						1																5
Tipula (S.) benesignata Mannheims, 1954							1*															5
Tipula (S.) goriziensis Strobl, 1893	1																3					9
Tipula (S.) rufina Meigen, 1818													1									5
Tipula (S.) subnodicornis (Zetterstedt, 1838)		1	1																			9
Blephariceridae																						
Liponeura cinerascens minor Bischoff, 1922			1																			5
Psychodidae																						
Bazarella subneglecta (Tonnoir, 1922)							1*				1											14
Berdeniella illiesi Wagner, 1973							1*				1											9
Pericoma sp.			1																			5
Satchelliella trivialis (Eaton, 1893)			2																			5
Empididae																						
Hemerodromia sp.							1*															5
Wiedemannia sp.	1			3			1*	3														14

Key: Categories of abundance: 1 – solitary (< 3 specimens per site); 2 – common (4–10 specimens per site); 3 – abundant (> 10 specimens per site). I – inlet, L – littoral, O – outlet; * larvae found in littoral near inlet. For site codes see Table 1.

Table 3. Eigenvalues and percent of variance for the first four ordination axes of RDA.

Axes	1	2	3	4	Total variance
Eigenvalues:	0.274	0.163	0.020	0.234	1.000
Species-environment correlations:	0.839	0.754	0.373	0.000	
Cumulative percentage variance					
of species data:	27.4	43.7	45.7	69.1	
of species-environment relation:	60.0	95.6	100.0	0.0	
Sum of all eigenvalues					1.000
Sum of all canonical eigenvalues					0.457

<u>Group 3</u> overlaps with group 2; the species *Berdeniella illiesi* found in Vyšné Temnosmrečinské pleso is not only acid sensitive but also prefers lower water temperature (Bulánková et al., 2001). The larvae probably could have drifted to the lake, because they live in running waters.

<u>Group 4</u> includes samples from outlets of submontane oligotrophic lakes (altitude 1705–1716 m a.s.l.) with pH 6.70–7.19, not threatened by acidification. Characteristic taxa are *Tricyphona* sp. and *Tipula* (*S.*) *goriziensis*, which were found only in lotic conditions.

Discussion

The macrozoobenthos of the Tatra lakes and the effect of acidification has been intensively investigated from the beginning of the 1980's (Krno et al., 1985; Krno, 1988, 1991; Šporka, 1992; Zaťovičová, 2002; Hamerlík, 2004; Bitušík, 2004). Attention was paid mostly to the chironomid assemblages, which are excellent indicators of past and recent environmental changes (Hamerlík, 2004).

Assemblages of preimaginal stages of Diptera (excl. Chironomidae, Simuliidae) of the Tatra lakes are characterised by the presence of eurytopic taxa, which tolerate cold and acid waters as well as several rare stenotopic species mainly of the family Tipulidae, subgenus *Savtshenkia*.

Except for scarce data about the occurrence of some Pediciidae and Limoniidae taxa, there have been

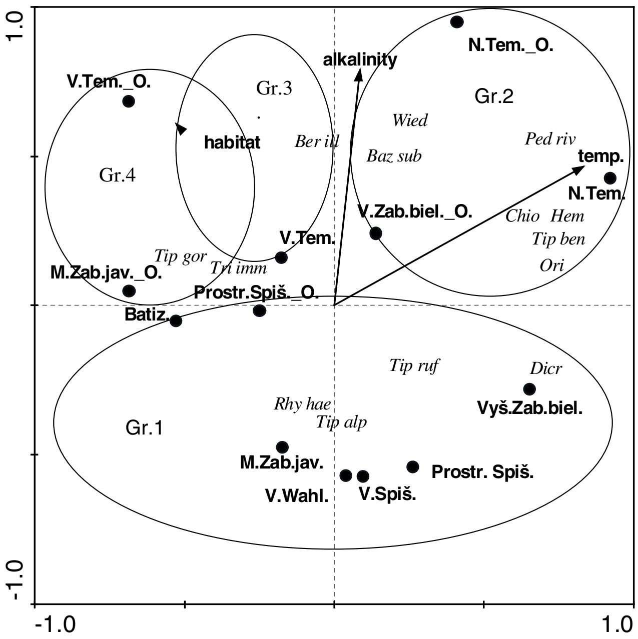

Fig. 1. RDA ordination diagram of the Diptera assemblages (excl. Chironomidae, Simuliidae). Environmental variables are represented by arrows: temp. – temperature, alkalinity, habitat – only binominal values. Abbreviations of taxa names are composed of the first three letters of genera and species names, for explanation see Table 2. For abbreviations of site numbers see Table 1; o – outlet.

no data on non-chironomid Diptera taxa from the Tatra lakes until now. Krno (1991) found *Dicranota* sp. in the littoral of the lakes Veľké spišské pleso, Prostredné spišské pleso, Vyšné Žabie bielovodské pleso, Nižné Žabie bielovodské pleso, Popradské pleso and *Orimargula alpigena* (Mik, 1883) in Zelené pleso. The present study confirms the occurrence of larvae of the genus *Dicranota* sp. in the lakes mentioned above (Tab. 2). Kownacki et al. (2000) found only two non-chironomid taxa of Diptera in high mountain Tatra lakes. Tarwid (1947) recorded the cold-stenothermic taxon *Chionea* in the Tatra Mts. *Rhypholophus* sp. represented a key taxon in a glacier-fed stream (Schültz et al., 2001).

Adults of species of the family Tipulidae, subgenus *Savtshenkia*, were found in the Tatra Mts by Martinovský (1984). He reported *Tipula* (*Savtshenkia*) *goriziensis* and *Tipula* (*S.*) *subnodicornis* from the Temnosmrečinská dolina valley (High Tatra Mts), *Tipula* (*Lunatipula*) *alpina* from the Jamnická dolina valley (Low Tatra Mts). Adult *Tipula* (*S.*) *benesignata* was found by Roháček et al. (1995) in the East Carpathian Mts province. Larvae of *Tipula* (*S.*) *benesignata* have been recorded in Slovakia only from the Turiec River (Bulánková & Degma, 1996). Savchenko (1961) recognized that larvae of this species live in small streams. We found this species in the littoral zone of Nižné Temnosmrečinské pleso, but close to inlet, so that the larvae probably could have drifted to the lake. Savchenko (1961) also stated that larvae prefer mosses in wet forests and stones covered with moss in small streams.

Tipula (*S.*) *subnodicornis* was also found by Martinovský (1984) in the Temnosmrečinská dolina valley. Savchenko (1961) stated that adults of this species occurred in the High Tatra Mts at the end of August. Larvae live in raised bogs with *Eriophorum vaginatum*, *Sphagnum* sp., *Vaccinium* sp. and also in mountain streams in small, shaded valleys. We found larvae of *Tipula* (*S.*) *subnodicornis* in the inlet of Nižné Jamnícke pleso and Vyšné Račkove pleso.

The only specimen of *Tipula* (*S.*) *rufina* was recorded in the outlet of Vyšné Žabie bielovodské pleso lake. This species is rare in England; its occurrence is restricted to Essex, with records from Epping Forest (http://www.essexfieldclub.org.uk/ERDlist/ERDB.htm). Its larvae prefer streams rich in mosses (Theowald, 1967). Species identification of *Tipula* (*S.*) *rufina* is tentative as it is based only on larvae; it should be confirmed by identification of the adult stage.

Krno (1991) determined 11 characteristic macroinvertebrate assemblages of several types of Tatra lakes. He found *Dicranota* sp. and *Orimargula alpigena* in subalpine oligotrophic lakes with heavy flow.

On the basis of benthic material obtained within the framework of the EMERGE project, Krno et al. (2006) recognized five types of Tatra lakes according to a CCA biplot:

A) Strongly acidified lakes – no aquatic Diptera were found there.

B) Alpine acidified lakes – consisting of the same sites as group 1 (Fig. 1). Alpine species like *Tipula* (*L.*) *alpina* and *Tipula* (*S.*) *rufina*, which prefer slightly acid waters, were found in this habitat. The bottom of these lakes is covered with particulate organic matter – a microhabitat suitable for *Dicranota* sp. and *Rhypholophus* sp.

C) Alpine non-acidified lakes – not statistically tested; acid sensitive taxa like *Pedicia* (*C.*) *rivosa*, *Tipula* (*S.*) *goriziensis* and *Wiedemannia* sp. were recorded in the inlet of Horné Roháčske pleso.

D) Subalpine acidified lakes – only the ubiquitous taxon *Dicranota* sp. was found in this habitat.

E) Subalpine non-acidified lakes – the characteristic Diptera species is *Pedicia* (*C.*) *rivosa*. According to RDA it was confirmed that this species lives in lakes not threatened by acidification (group 2).

Lepori et al. (2003) used detrended canonical correspondence analysis to assess the biological differences between streams representing different acid-based groups. DCA showed that the streams sensitive to episodes had different invertebrate assemblages in comparison with well buffered sites or soft-water stable streams in the Swiss Alps. Empididae were scarce in streams sensitive to episodes (pH 6.7–7.1). The same response was confirmed in the Tatras for *Wiedemannia* sp. and *Hemerodromia* sp. (Empididae).

Bitušík et al. (2003) ordinated the same Tatra lakes by CCA and described characteristic chironomid assemblages for three types of these lakes. Acidified ones were found to have a specific taxonomic composition regardless of differences in altitude. According to our results, acidified alpine and subalpine Tatra lakes, occuring at altitude of 1705–2145 m a.s.l., have specific taxonomic composition.

Acknowledgements

The research was supported by a project of European Commission (EMERGE EVK-CT 1999-00032) under the 5th Framework Programme and by the Slovak Grant Agency for Science, grant No. 1/1292/04. We thank Dr. F. Šporka for providing the hydrobiological material from EMERGE.

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Received July 15, 2005
Accepted May 9, 2006