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Blackfly (Diptera, Simuliidae) communities and species richness estimation in Carpathian montane streams

Research Article

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Abstract: The present work gives the result of blackfly fauna research of the Slovenský raj (West Carpathians, Slovakia). Our aim was to describe the composition of blackfly communities, find indicator species for communities, describe environmental factors affecting communities and determine the potential changes in species richness. Research was carried out in 2007 and 2008. The presence of 22 species of blackflies was confirmed at 20 sites in the area of Slovenský raj. 12 species were recorded for the first time in this area. The potential for further increase in diversity was calculated by a nonparametric estimation of species richness. Two main groups of sites with their typical blackflies communities were indentified using a TWINSPAN analysis. The presence of *Simulium ornatum, S. variegatum* and *S. argyreatum* was typical in larger streams in broad valleys. The absence or low abundance of these species was typical for smaller streams in canyons. Based on the species composition of blackflies communities, we identified 6 groups of sites: 1. anthropogenically disturbed submountain rivers (typical species: *Simulium ornatum, S. reptans, S. equinum*), 2. undisturbed metarhithral (typical species: *Simulium bertrandi, S. codreanui, S. costatum, S. vernum, S. argenteostriatum, S. degrangei, S. argyreatum, S. variegatum*), 3. undisturbed hyporhithral (typical species: *Simulium trifasciatum, S. tuberosum*), 4. undisturbed epirhithral (typical species: *Prosimulium hirtipes, P. rufipes*), 5. hypocrenal (typical species: *Simulium cryophilum, S. monticola*) and 6. anthropogenically disturbed epirhithral (typical species: *Simulium brevidens, S. maximum*). The most important environmental factors explaining differences in species composition like altitude, flow speed, pH, conductivity, oxygen saturation, sulphates concentration and presence of riparian vegetation were identified by the CCA analysis.

Keywords: *Simuliidae • Carpathians • Slovakia • Environmental factors*

1. Introduction

Blackflies are an important part of the macrozoobenthos communities in flowing waters as considerable element of a food chain as prey for wide range of invertebrates [1-3]. Changes in the species composition can be closely related to changing environmental conditions in the longitudinal profile of streams and eutrophication [4]. The composition of blackfly communities reflects differences between species-specific ecoregions [5] and blackflies can be used as indicator organisms of morphological stream degradation [6]. Specific requirements of individual species and changes in the composition of communities as a result of hydromorphological degradation of streams were examined by Lautenschläger and Kiel [7]. McCreadie and Adler [5] examined both the relationship between species composition of preimaginal blackflies communities and the landscape (ecoregions) through which their stream habitats flow.

Although the Slovakian blackflies fauna is generally well known, sparse data are available for the area of Slovenský raj. All data from this area are presented in more generally in dipterological literature [8,9], or they are summarized in a paper by Illéšová [10]. Species composition of blackfly communities of Slovenský

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raj could be comparable to other mountain areas of Slovakia, which blackfly fauna is better known. According to hypsometric and hydrological conditions, flows in the Slovenský raj belong to sub-mountain (500-800 m a.s.l.) or mountain (800-1500 m a.s.l.) altitudinal zones. Jedlička established five faunal groups of blackflies for all landscape units of Slovakia [11]. The author recorded the occurrence of 26 species in sub-mountain zone, lower basins and lower mountains. 21 species were reported from mountain areas. Blackflies communities of upper section of the River Hron, which drains the western part of Slovenský raj, were researched by Illéšová and Halgoš [12]. Authors confirmed 16 species of blackflies at four sites. Illéšová *et al*. found 9 species in Zubrovica stream [13], which belongs to investigated flows of our research as well. There were 11 species found in the upper section of the Hron River near Telgárt. Among other works exploring blackflies communities in mountain conditions of Slovakia, the paper of Jedlička should be mentioned [14]. He found 15 species in the river Belá (High Tatras Mountains), and Illešová *et al*. reported 11 species from High Tatras Mountains [15]. Jedlička confirmed 10 species from Slovenský raj [8], Stloukalová and Jedlička found 9 species [9]. Initial results of our research document the occurrence of 20 species [16].

Halgoš *et al*. studied the effects of selected environmental factors on the composition of blackfly communities in sub-mountainous type of streams, and defined three groups of environmental variables influencing the distribution of individual species [4]. The first group consisted of variables related to eutrophication and organic pollution, the second group consisted of factors related to the physiographic conditions and the third group was characterized by damming. Based on these three groups of environmental variables, the authors found three groups of blackflies communities.

Our paper presents results of hydrobiological research on the mountain and submountain streams of Slovenský raj. The main aim of this paper was to i) describe the composition of blackflies communities, ii) find indicator species for communities, iii) describe environmental factors affecting communities and iv) determine potential changes in species richness.

2. Experimental Procedures

2.1 Study area

Slovenský raj is a mountain landscape subassembly in Spišsko-Gemerský Kras (West Carpathians), and most of its territory is a part of the national park. The area is characterized by mountains with an altitude of 800 to 1 200 m a.s.l., broken by valleys of rivers Hornád and Hnilec tributaries. Valleys are characterized as narrow canyons and gorges with frequent river jumps and waterfalls. Frequent occurrence of groundwater, karst hydrology and springs is typical for the area. From the hydrological point of view, Slovenský raj is a relatively homogeneous area. The vast majority of the area is part of Hornád river basin, only the western region near the village Telgárt belongs to Hron River basin. Hornád river basin is divided into two parts, which are drained by Hornád itself and its biggest tributary Hnilec. Hornád has an average overflow rate of 6.2 $m^3 s^{-1}$, Hnilec has an average overflow rate of 0.95 $m^3 s^{-1}$. The river system reaches the highest overflow rates in spring (March–May), when the snow is melting [17,18].

The locations of research sites are shown in Figure 1, the abiotic characteristics of individual sites are in Table 1

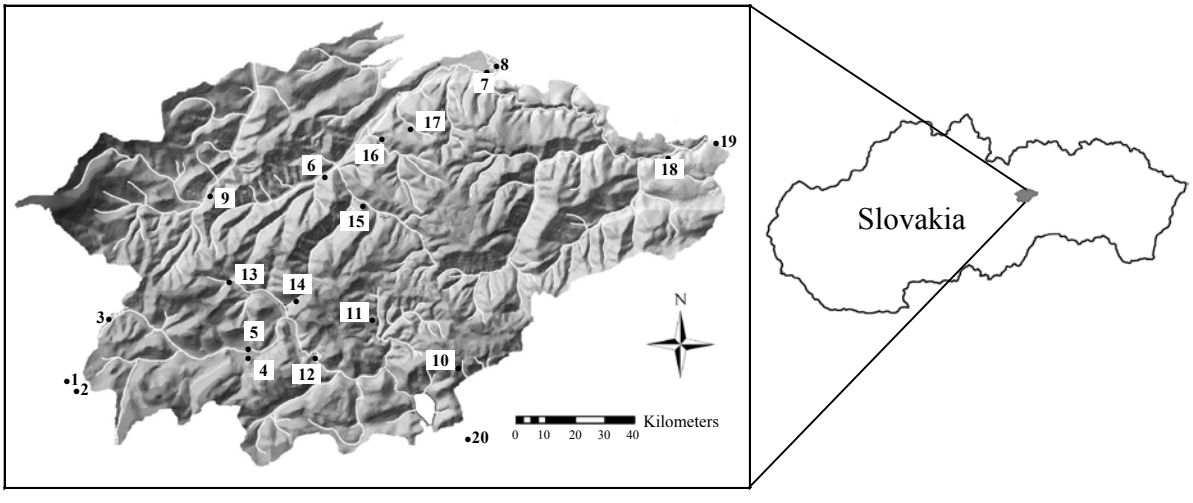

Figure 1. Map of sites in study years 2007 and 2008. (Designation of sites is following Table 1).

Code	Site	DFS	Longitude	Latitude	Altitude (m a.s.l.)	Width (m)	Depth (m)	Flow speed ($m.s^{-1}$)	Bottom	Overshadow (%)	Riparian vegetation
1	Zubrovica – near Telgárt	7087c	20°10´44´´	48°51´15´´	940	2	0.2	1.2	mesolit., akal	0	+
2	Hron – near Telgárt	7087c	20°12´43´´	48°51´27´´	889	1.5	0.2	0.98	akal	80	+
3	Hnilec - Pusté pole	7087c	20°14´13´´	48°52´56´´	913	3.5	0.3	0.83	mesolit.	70	
4	brook – near Dobšinská Ice Cave	7088b	20°18´10´´	48°52´20´´	855	2.5	0.1	1.36	mesolit.	80	
5	Hnilec – near Dobšinská Ice Cave	7088b	20°18´19´´	48°52´31´´	845	5	0.5	1	akal	30	+
6	Veľká Biela voda - Štvrtocká Píla	7087b	20°19´27´´	48°55´41´´	628	3.5	0.3	0.72	mesolit.	70	
7	Veľká Biela voda - Podlesok	6990b	20°23´59´´	48°57´45´´	540	7	0.5	0.58	mesolit., akal	0	+
8	Hornád - Hrabušice	6990b	20°24´10´´	48°57´44´´	535	9	0.4	0.5	akal, pelal	0	+
9	Vernársky brook – near Vernár	7087b	20°17´08´´	48°55´51´´	760	3	0.3	1.32	mesolit.	70	
10	Zejmar – Zejmar Yardang	7088d	20°23´48´´	48°52´33´´	865	1	0.2	1.69	macrolit., megal.	80	
11	Strateník – near Stratená	7088b	20°20´29´´	48°52´26´´	868	2	0.2	1.4	mesolit.	90	
12	Hnilec – Stratenský Canyon	7088b	20°19´43´´	48°52´34´´	816	6	0.5	1	mesolit.	70	+
13	spring brook – Kopanec	7087b	20°17´35´´	48°53´37´´	796	0.7	0.05	0.97	mesolit., akal	0	+
14	spring brook – Blajzloch	7087b	20°19´05´´	48°53´25´´	655	1	0.1	1.12	mesolit.	70	
15	Sokol - Kamenné vráta	7088a	20°20´19´´	48°55´41´´	667	2	0.2	1.2	mesolit., megalit.	80	
16	brook – Stredné Piecky	7088a	20°21´08´´	48°56´31´´	639	2	0.3	1	mesolit., megalit.	90	
17	brook – Suchá Belá	7088a	20°22´03´´	48°57´20´´	609	1.7	0.3	1.26	mesolit., megalit.	80	
18	Hornád - Čingov	6990b	20°30´26´´	48°56´57´´	511	12	0.5	0.99	mesolit., akal	70	+
19	Hornád - Spišská Nová Ves	6990b	20°31´26´´	48°56´51´´	460	15	0.7	0.69	akal	0	+
20	Hnilec - Mlynky	7088d	20°25´36´´	48°51´02´´	741	6	0.5	0.6	akal	0	+

Table 1. Characteristics of abiotic factors at the study sites.

and selected physical and chemical environmental parameters are in Table 2. Flows in Slovenský raj are characterized by high degree of haleness from hydromorphological point of view. Despite this, there is evidence of anthropization in some sites. The higher parts are affected mainly by tourism, as tourist trails are often in close proximity to flows, and eventually slide directly through the stream channel. This effect is shown especially by higher value of nitrates (Table 2). In the submountain part of flows, there are frequent impacts of urbanization and agriculture, mainly on Hornád river.

2.2 Material

Preimaginal stages of blackflies were collected from 20 sites (Figure 1), three times per year (in vegetal season from April to October) during years 2007 and 2008. We selected 10 sites (1–10) which represent typical flows of Slovenský raj and 10 additional sites (11–20) to cover maximum of studied area. The material was obtained by individual collecting from particular microhabitats with semiquantitative sampling methods, with a sampling duration of 15 minutes for each site. Preimaginal stages of blackflies were determined to species level, using Knoz [19,20] and Jedlička *et al*. [21]. The nomenclature of blackflies was used according to Jedlička and Knoz [22]. Part of the material was prepared for permanent microscopic slides using Kramář's method (dehydrating in an aqueous solution of phenol and mounted in a Canadian balsam).

2.3 Data analysis

For the classification of sites, the TWINSPAN analysis (Two-way indicator species analysis) was used according to Hill [23]. Identification of indicator species was based on qualitative data. In order to take quantitative data into account, we applied the concept of pseudo-species (with the level of division), in which each species may be listed as several pseudo-species, according to the quantity of the sample. Pseudo-species are indicated in case, if the quantity of species exceeds the corresponding level of dividing. We chose the following levels: 1 (0-2%), 2 (2-5%), 3 (5-20%), 4 (20% or more). We identified blackfly communities according to this principle as well.

Selected physicochemical parameters were determined (pH, conductivity, O_2, NH_4^{-1}, NO_3^{-1}, SO_4^{-2}, PO_3^{-1}) for 10 representative sites (sites 1 to 10). Other measured and analyzed variables at all sites were: altitude, maximal temperature, flow width, flow depth, flow speed, character of the bottom, % of overshadow and presence or absence of riparian vegetation. Data were analyzed by the canonical correspondence analysis (CCA) in the program Canoco 4.0 for Windows and CanoDraw 4 for Windows, by using the "forward selection", according to Ter Braak and Šmilauer [24], in order to determine the factors of greatest influence.

For an estimation of species richness, we used the program EstimateS 8.0 [25]. In the analysis of nonparametric estimate of species richness (based on the presence and absence of species at site), we used ICE and CHAO2 [23]. During the estimation, values from 3 to 10 were used as limits for infrequent species. In estimates close to the value of 5, species present in less than 10% of locations were considered infrequent.

3. Results

3.1 Species composition

We confirmed 22 blackfly species in the area of Slovenský raj (Table 3). 12 of these species were recorded for the first time in this area (marked with *).

Site	O_2 (mg.l^{-1})	O_2 (%)	NH_4^{-1} (mg.l^{-1})	NO_3^{-1} (mg.l^{-1})	SO_4^{-2} (mg.l^{-1})	PO_3^{-1} (mg.l^{-1})	Conductivity (μ.cm^{-1})	pH	Max. temp. (°C)
1	10.90	98.0	0.05	2.9	9.3	0.03	54.3	7.81	15
2	10.98	99.0	0.05	2.4	21.5	0.03	240.0	7.86	15
3	11.52	98.8	0.05	2.5	12.5	0.03	168.3	7.97	16
4	11.00	98.0	0.05	6.6	45.9	0.03	393.0	8.10	13
5	10.80	93.2	0.05	4.2	28.8	0.03	294.0	8.26	11
6	11.40	100.5	0.05	4.2	13.1	0.03	397.0	8.34	14
7	12.56	108.5	0.05	3.7	13.6	0.03	397.0	8.43	15
8	13.00	110.0	0.08	5.0	59.9	0.15	450.0	8.45	19
9	11.02	97.6	0.05	3.4	34.9	0.07	377.0	8.25	13
10	11.36	100.6	0.05	6.3	13.2	0.03	338.0	8.28	12

Table 2. Physical and chemical characteristics of selected representative sites.

Species	Sites																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
P. hirtipes (Fries, 1824)	3.82	1.49			31.47				3.23	90.04	57.14				18.18	13.33				
P. rufipes (Meigen, 1830)	11.81	6.44	2.20	3.94						8.43	9.52						98.21			
P. tomosvaryi (Enderlein, 1921)*			14.84					23.76											3.96	
S. aureum (Fries, 1824)*					0.54															0.97
S. bertrandi (Grenier and Dorier, 1959)*	0.35																			
S. brevidens (Rubtsov, 1956)*	1.39	3.96				9.76					14.29		50.00	6.38						
S. codreanui (Serban, 1958)*	0.35		0.55																	
S. costatum (Friedrichs, 1920)*		3.47																		
S. cryophilum (Rubtsov, 1959)	5.56	9.41	0.55			2.44							50.00	51.06	27.27	86.67				
S. vernum (Macquart, 1838)	4.17	16.34	3.85		4.50												1.79			15.53
S. argenteostriatum Strobl, 1898	2.08				2.16															
S. degrangei Dorier and Grenier, 1960*					0.90															
S. ornatum Meigen, 1818	0.35	24.26					56.00	12.21	1.08										22.03	78.64
S. trifasciatum Curtis, 1839		1.49		1.97	0.90	17.07		2.97											0.99	
S. reptans (Linnaeus, 1758)*	0.69	0.50						4.29											1.73	
S. tuberosum (Lundström, 1911)*					0.90	2.44	1.00													4.85
S. vulgare Dorogostaisky, Rubtsov et Vlasenko, 1935*					0.72															
S. argyreatum Meigen, 1838	52.08	14.85	73.08	41.38	22.66	43.90	43.00	17.49	8.06	1.15		100							12.62	
S. maximum (Knoz, 1961)*	1.04		1.65							0.38	19.05				54.55					
S. monticola Friedrichs, 1920	12.50	12.87			2.52	24.39			8.60					42.55				100		
S. variegatum Meigen, 1818	3.82	4.95	3.30	52.71	32.73			33.66	79.03										40.59	
S. equinum (Linnaeus, 1758)*								5.61											18.07	
Number of species	14	12	8	4	11	6	3	7	5	4	4	1	2	3	3	2	2	1	7	4
Total number of individuals	288	202	182	203	556	82	100	303	372	261	21	2080	2	47	11	15	56	81	404	103

Table 3. Blackflies dominance (according to Pelikán [27]) at study sites.

** New species for the area of Slovenský raj*

Species with the highest frequency of occurrence were *Simulium argyreatum* (60%), *Prosimulium hirtipes* (40%), *S. cryophilum* (40%), *S. variegatum* (40%). Species *Simulium bertrandi*, *S. costatum*, *S. degrangei* and *S. vulgare* were recorded with rare occurrence (frequency less than 5%).

In faunal research, the knowledge entirety of species composition can be a problem. It is possible to solve this task with a non-parametric estimation of species richness (Figure 2). This analysis shows that the progress of Coleman's curves does not suggest the heterogenity of blackflies species at individual sites, compared to the curves of identified species (Coleman curves "Coleman" do not exceed the curves of cumulative number of species "Sobs Cumul"). The number of species, expressed by the curve "Coleman" converges to the expected number of about 24 species after an initial increase to the inflection point (about 8 sites). However, it does not reach this value and is stabilized at the final number of 22 species. Species richness estimation (ICE) reaches the value of 23.94 and thus predicts the possibility of further, although not significant, increase in the number of species in the studied area. The confidence interval for the species richness estimation is in the range from 3.58 to 24.59%.

3.2 Clustering of sites according to species composition

The first dichotomy (Figure 3) divides the study sites into two groups. The first group consists of smaller streams and streams flowing through canyons. The second group consists of larger streams flowing through wider valleys. The first group is characterized by the absence of *Simulium ornatum*, *S. variegatum* and the low value of dominance of *Simulium argyreatum*. Most sites of this group are located in the upper sections of streams at higher altitudes. This group is divided into two subgroups. *Prosimulium rufipes* and *P. hirtipes* are indicators of a highly turbulent streams flowing through canyons. *Prosimulium rufipes* indicates a preserved epirhithral. *Prosimulium hirtipes* is typical for epirhithral

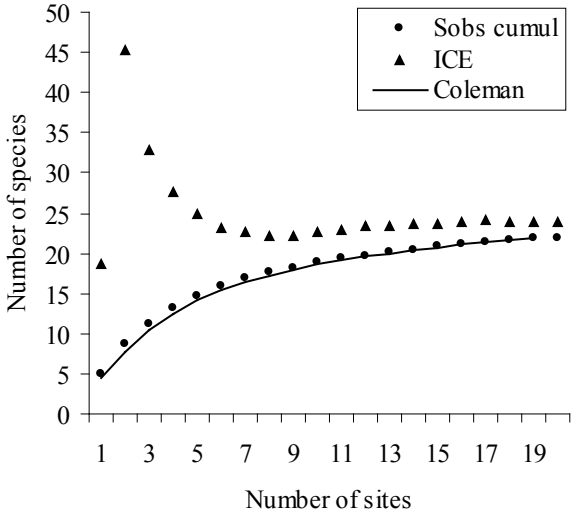

Figure 2. Estimation of species richness: identified (Sobs cumul) and expected (Coleman, ICE) number of species.

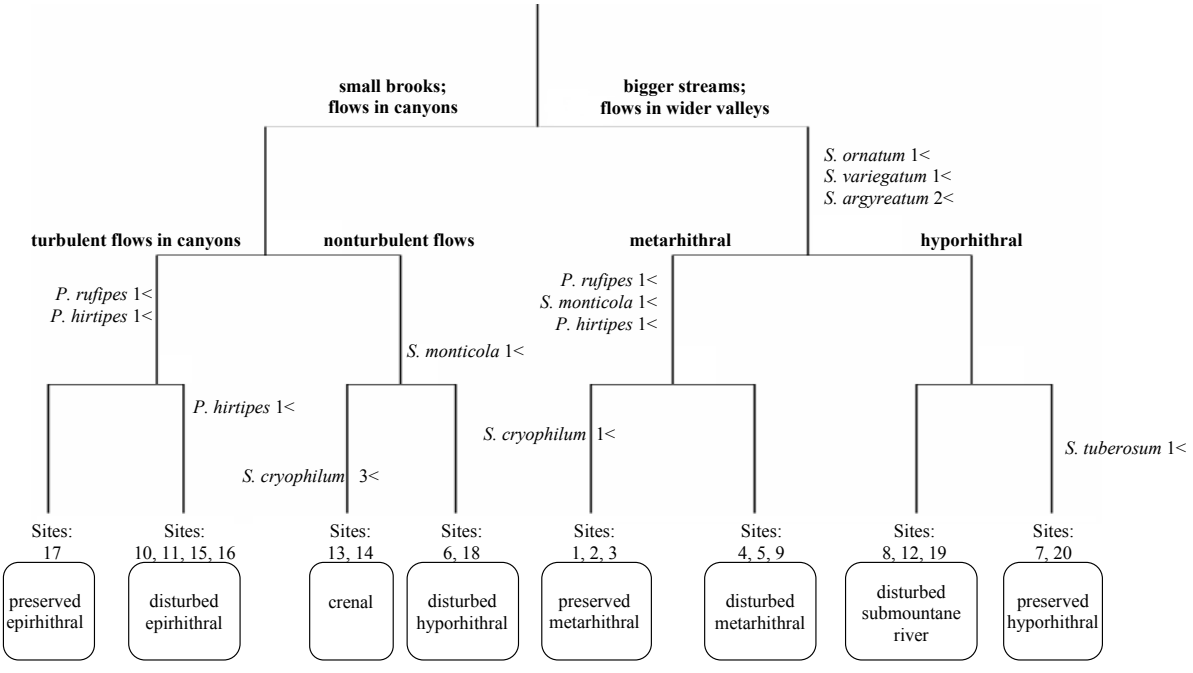

Figure 3. Dendrogram of blackflies communities, according to TWINSPAN analysis.

in small canyon streams, heavily influenced by tourism. *Simulium monticola* characterizes the group of non-turbulent streams, *Simulium cryophilum* was indicator species for the crenal zone. The absence of this species indicates partly anthropogenically influenced (by tourism) canyon streams belonging to the zone from hyporhithral to metarhithral.

Simulium ornatum, *S. variegatum* and *S. argyreatum* group determined submountainous rivers and larger streams flowing through wide valleys. *Prosimulium rufipes*, *P. hirtipes* and *Simulium monticola* were indicators for metarhithral, where *Simulium cryophilum* was an indicator of preserved upper sections. Absence of this species indicated an anthropogenically disturbed zone of the lower metarhithral. *Simulium tuberosum* determined the zone of preserved upper hyporhithral. The absence of this species indicated a strongly anthropogenically affected zone of lower hyporhithral.

3.3 Blackfly communities

Data from selected 10 representative sites (sites 1–10, Table 2) were analyzed by CCA. The most important variables correlated with the first (horizontal) axis (Table 4, Figure 4) of standardized CCA, which explains 28% of total variance and is determined mostly by physical variables (altitude and flow speed) and by the percentage of oxygen saturation. The second axis (vertical) explains 25% of total variance and is determined by chemical factors (disulphates, pH, conductivity). A significant factor, from categorical variables, was the presence of riparian vegetation, which is an important microhabitat for preimaginal stages of blackflies. Flow speed, pH, conductivity and partially value of SO_4^{-2} were positively correlated with altitude. Percent oxygen saturation and the presence of riparian vegetation negatively correlated with altitude.

Axes	1	2	3	4	Total variance
Eigenvalues	0.282	0.245	0.126	0.110	1.000
Species-environment correlations	0.968	0.966	0.924	0.957	
Cumulative percentage variance					
of species data	28.2	52.7	65.3	76.3	
of species-environment relation	33.4	62.4	77.2	90.3	
Sum of all unconstrained eigenvalues					1.000
Sum of all canonical eigenvalues					0.845

Table 4. Eigenvalues and percent variance explained for first four ordination axes of CCA.

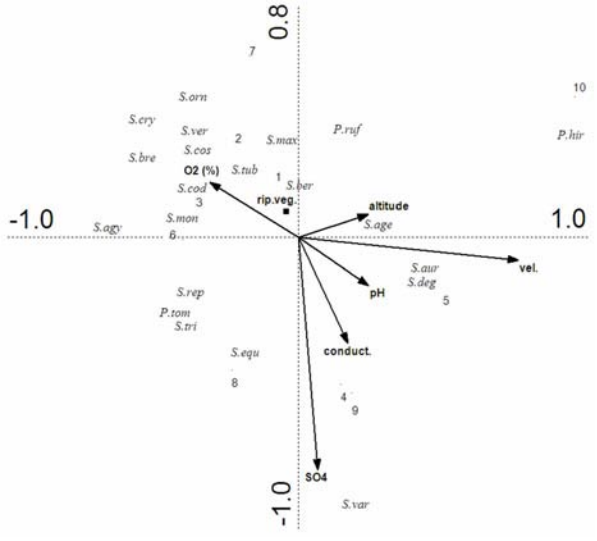

Figure 4. Ordination of 10 representative sites by CCA. Groups of species were determined by Twinspan analysis. (Abbrevitations: *Phir – Prosimulium hirtipes, Pruf – P. rufipes, Ptom – P. tomosvaryi, S.agy – Simulium argyreatum, S.age – S. argenteostriatum, S.aur – S. aureum, S.ber – S. bertrandi, S.bre – S. brevidens, S.cod – S. codreanui, S.cos – S. costatum, S.cry – S. cryophilum, S.deg – S. degrangei, S.equ – S. equinum, S.max – S. maximum, S.mon – S. monticola, S.orn – S. ornatum, S.rep – S. reptans, S.tri – S. trifasciatum, S.tub – S. tuberosum, S.var – S. variegatum, S.ver – S. vernum*).

Data from Slovenský raj were analyzed by Twinspan (with use of the concept of pseudo-species) and 6 types of blackflies communities were identified, with their characteristics corresponding with CCA analysis of sites (Figure 4).

3.3.1 Community of predominant species Simulium ornatum, S. reptans, S. equinum

The community determined sub-mountainous rivers (lower hyporhithral) with strong anthropization, in 460-535 m a.s.l. The river bottom consists of gravel and clay, the width of the river is 9-15 m, the flow speed is 0.50–0.69 m s^{-1} and the maximum temperature is 19°C. The community also included, except for the above-mentioned identifying species, *Prosimulium tomosvaryi, Simulium trifasciatum, S. argyreatum, S. variegatum.* The average number of species was 7.

3.3.2 Community of predominant species Simulium bertrandi, S. codreanui, S. costatum, S. vernum, S. argenteostriatum, S. degrangei, S. argyreatum, S. variegatum

The community characterized undisturbed mountain brooks (metharithral) in 540–940 m a.s.l., width of the flows is 1.5–7.0 m, flow speed is 0.58–1.36 m s^{-1} and maximum temperature is in scope of 11–16°C. This community included species *Prosimulium hirtipes, P. rufipes, Simulium brevidens, S. cryophilum, S. ornatum, S. reptans, S. maximum, S. monticola* as well. Average number of species is 7.25 (minimum: 1, maximum: 14 species).

3.3.3 Community of predominant species Simulium trifasciatum, S. tuberosum

The community characterized undisturbed bigger sub-mountainous and mountainous flows (upper hiporhithral) in 511–741 m a.s.l. Width of the flows is in range 3.5–12 m, flow speed is 0.60–0.99 m s^{-1} and maximum temperature is 14°C. The community included also species *Prosimulium hirtipes, Simulium aureum, S. vernum, S. argenteostriatum, S. degrangei, S. vulgare, S. argyreatum, S. monticola, S. variegatum.* Average number of species is 3.6 (minimum: 1, maximum: 6 species).

3.3.4 Community of predominant species Prosimulium hirtipes, P. rufipes

The community determined undisturbed upper parts of streams (epirhithral) flowing through canyons in 609–865 m a.s.l. High flow speed (1.0–1.69 m s^{-1}) and turbulency are characteristic for these streams. Width of the flows is less than 2 m and maximum temperature up to 12°C. The community included, except above-mentioned identifying species, also species *Simulium brevidens, S. ornatum, S. argyreatum, S. maximum, S. monticola, S. variegatum*. Average number of species is 2.75 (minimum: 2, maximum: 4 species).

3.3.5 Community of predominant species Simulium cryophilum, S. monticola

The community was typical for hypocrenal zone in 655–796 m a.s.l. Width of flows is 0.7–1 m, flow speed is 0.97–1.12 m s^{-1}. The community included also species *Simulium brevidens, S. trifasciatum, S. tuberosum, S. argyreatum.* Average number of species is 2.5 (minimum: 2, maximum: 3 species).

3.3.6 Community of predominant species Simulium brevidens, S. maximum

The community was typical for upper parts of flows (epirithral) with strong anthropization (tourism), in 868 m a.s.l. Width of flow is 2 m, flow speed is 1.40 m s^{-1}. The community included also species *Prosimulium hirtipes, P. rufipes.* Average number of species is 4. Basic characteristics of communities are resumed in Table 5.

4. Discussion

Stloukalová and Jedlička confirmed 44 species of blackflies in the Carpathian bioregion in Slovakia [28]. We collected a total of 22 species in the territory of Slovenský raj, which is half of the listed species richness. All 10 species [8,9] from the study area were confirmed by our research. Finding species *Simulium bertrandi* was particularly interesting. Stloukalová and Jedlička reported this species from Fatra and High Tatras Mountains area and they also predicted its occurrence in mountainous and sub-mountainous streams [9]. Species *Simulium codreanui* was observed in Slovakia only in rhithral of sub-mountain and mountain zone in Low Tatras and Vtáčnik Mountains [9]. Both mentioned species have typical occurrence in hypocrenal and epirithral in submountain areas and they are indicators of oligosaprobic to xenosparobic conditions [10].

Possibility of raising of blackfly species number in study area was confirmed by non-parametric estimating of species richness. We found out that there is possibility for increase in number of species, but further research would be needed. Similar results were published by Jedlička and Halgoš in the territory of Malé Karpaty Mountains. [29]. They also confirmed that the number of species raised. New species in Slovenský raj could be expected from surrounding areas with similar environmental conditions. Illéšová *et al*. found 11 species of blackflies in Vysoké Tatry

No.	Identification species	Altitude (m a.s.l.)	Flow width (m)	Flow speed ($m.s^{-1}$)	Max. temp. (°C)	Additional species	Sites
1	*S. ornatum* *S. reptans* *S. equinum*	460 - 535	9 - 15	0,50 - 0,69	19	*P. tomosvaryi, S. trifasciatum, S. argyreatum, S. variegatum*	8, 19
2	*S. bertrandi* *S. codreanui* *S. costatum* *S. vernum* *S. argenteostriatum* *S. degrangei* *S. argyreatum* *S. variegatum*	540 - 940	1,5 - 7	0,58 - 1,36	11 - 16	*P. hirtipes, P. rufipes, S. brevidens, S. cryophilum, S. ornatum, S. reptans, S. maximum, S. monticola*	1, 2, 3, 4, 5, 7, 9, 12
3	*S. trifasciatum* *S. tuberosum*	511 - 741	3,5 - 12	0,60 - 0,99	14	*P. hirtipes, S. aureum, S. vernum, S. argenteostriatum, S. degrangei, S. vulgare, S. argyreatum, S. monticola, S. variegatum*	6, 18, 20
4	*P. hirtipes* *P. rufipes*	609 - 865	1 - 2	1,0 - 1,69	12	*S. brevidens, S. ornatum, S. argyreatum, S. maximum, S. monticola, S. variegatum*	10, 15, 16, 17
5	*S. cryophilum* *S. monticola*	655 - 796	0,7 - 1	0,97 - 1,12		*S. brevidens, S. trifasciatum, S. tuberosum, S. argyreatum*	13, 14
6	*S. brevidens* *S. maximum*	868	2	1,40		*P. hirtipes, P. rufipes*	11

Table 5. Characteristics of communities.

Mountains [15]. The composition of communities was similar to these in Slovenský raj, but differed in the absence of alpine species *Twinia hydroides* and species *Simulium carthusiense, S. oligotuberculatum.* Considering the relatively short distance between Vysoké Tatry Mountains and Slovenský raj, occurrence of above-mentioned species is expected. The main influence on changing of species composition, occurrence of new species respectively, could have an anthropic factor, too [30]. When estimating the species richness in relation to undisturbness of streams, Armitage *et al*. found that the abundance of blackflies in regulated mountainous streams was distinctively lower than at undisturbed sites with similar environmental conditions [31]. We observed a similar situation in the territory of Slovenský raj, although tourism had negative influence.

Illéšová *et al*. found 9 species of blackflies in the stream Zubrovica [13]. 14 species were collected by our research, while all the species listed by above-mentioned authors were confirmed. The other species we recorded were *Simulium brevidens, S. codreanui, S. vernum, S. argenteostriatum* and *S. maximum.* Fluctuations of blackfly diversity at this site could be influenced by significant changes of environmental conditions of the stream, which are related to windstorm calamity and its direct effect (especially raised exposition to sunlight and related raising of temperature).

Research of the species composition of blackfly communities in sub-mountainous and mountainous rivers in Slovakia has been carried out by Illéšová and Halgoš [32]. They found 10 species of blackflies in Turiec River. Their results agreed with ours, suggesting that typical species for metarhithral and upper hyporhithral were *Prosimulium hirtipes, Simulium variegatum, S. argyreatum* and *S. monticola.* Species characteristic for hyporhithral were *Simulium ornatum, S. reptans* and *S. equinum.* Similar species composition of communities in corresponding parts of streams observed Illéšová *et al*. in Hron River, as well [13]. They identified species *Simulium equinum* as indicator species for dividing stream in lower and upper hyporhithral. The species *Simulium tuberosum* is an indicator in conditions like in the Slovenský raj, which divides indisturbed upper hyporhithral and lower hyporhithral with strong environmental anthropization. This situation is caused by higher water quality in mountain zone of study area and followed by a shift of indicating importance to more sensitive species.

Krno divided sites into two zones crenal and rhithral on higher hierarchic level based on composition of communities of macroinvertebrates (including blackflies) in small stream Ľupčianka [33]. He divided rhithral in two sections on lower hierarchic level. The species *Prosimulium rufipes* and *Simulium monticola* dominated the first section. The author divided the second section in two subgroups. Species *Prosimulium rufipes* reached high value of abundance in first subgroup. The species *Simulium reptans* dominated in second subgroup and species with high abundance were also *S. variegatum* and *S. ornatum.* We observed similar structure of communities in relationship to biotope classification of streams in the territory of Slovenský raj. Illéšová and Jedlička identified two types of communities based on the composition of blackflies communities in streams of Veľká Fatra [34]. The first type, with dominant species *Prosimulium rufipes* and *Simulium monticola,* were characterstic for epirhithral. Species *Simulium argyreatum, S. variegatum* and *S. argenteostriatum* were characterstic for metarhithral. Authors observed increasing abundance of the species *Simulium variegatum* in metarhithral with strong anthropization, which we confirmed in streams in the territory of Slovenský raj.

Glathaar identified 5 groups of streams based on the blackflies communities [35]. Those 5 groups were mountain streams, forest streams, lowland rivers, meadow and field streams and streams outflowing of dams. The author did not mention the occurrence of metarhithral in the groups of streams and rivers. Hyporhithral was characterstic by the occurence of *Simulium reptans*, which was one of the indicator species of hyporhithral with anthropization influence in the territory of Slovenský raj, as well.

Lautenschläger and Kiel found out, that *Prosimulium hirtipes* and *Simulium argyreatum* are typical species and indicators of undisturbed upper sections of streams and they are sensitive to morphological degradation [7]. According to situation that the streams in Slovenský raj are undisturbed at all, if considering changes in morphology, we did not observed similar trend at those species. *Simulium ornatum* and *S. equinum* were identified by authors as tolerant to environmental anthropization. We found the species *S. ornatum* in quite undisturbed upper sections of streams. Species *S. equinum* was similarly tolerant to anthropization.

Halgoš *et al*. observed that distribution of blackflies in longitudinal zonation of sub-mountainous streams was determined by three groups of environmental factors [4]. First group of factors was related to eutrophization of streams and organic pollution. Second group was determined by physiographic variables. The third most important factor, observed by the authors, was building dams in streams. The influence of anthropization, as one of the most important factors determining species composition of blackflies communities in sub-mountainous streams, was observed by Bulánková *et al*., as well [36]. We observed similar situations in Slovenský raj, where blackflies communities were determined by the level of disturbance, respective origin, and physiogeographic conditions at selected sites. Building dams, as a factor, was not observed, as there was not such an influence in streams studied in this research. Illéšová *et al*. showed in mountainous streams as most important determining factors: flow speed, stream flow and maximum temperature [15]. The influence of altitude, flow speed and the presence of riparian vegetation, as a part of substratum, was confirmed in the conditions of Slovenský raj.

5. Conclusions

During our research of Slovenský raj we noted the occurrence of 22 species, 12 of which are new for this area. By estimating potential diversity changes we discovered the possibility of species richness increasing in future. The most common species were *Simulium argyreatum, Prosimulium hirtipes, S. cryophilum* and *S. variegatum*. Species with rare occurrence included *Simulium bertrandi, S. costatum, S. degrangei* and *S. vulgare*. We discovered 6 types of blackfly communities with their typical indicator species. By clustering sites on the basis of their specific composition, the main indicator species were *Simulium ornatum, S. reptans* and *S. equinum* in submountain rivers with strong anthropization, *Simulium bertrandi, S. codreanui, S. costatum, S. vernum, S. argenteostriatum, S. degrangei, S. argyreatum* and *S. variegatum* in mostly undisturbed matharithral, *Simulium trifasciatum* and *S. tuberosum* in undisturbed hyporhithral, *Prosimulium hirtipes* and *P. rufipes* in undisturbed epirhithral, *Simulium cryophilum* and *S. monticola* in hypocrenal, *Simulium brevidens* and *S. maximum* in epirhithral with marks of anthropization. According to canonical correspondence analysis, the most efficient environmental variables affecting blackfly communities were altitude, flow speed, percentage of oxygen saturation, disulphates, pH, conductivity and the presence of riparian vegetation as suitable substrate for preimaginal stages of blackflies.

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