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Biologia **72**/11: 1229—1239, 2017
Section Zoology
DOI: 10.1515/biolog-2017-0152
Review

Identifying white spots on the roadmap of Late Pleistocene and Holocene palaeolimnology in Slovakia: Review and future directions

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Abstract: Paleolimnological research in the territory of Slovakia has relatively short history with the beginning in the 1990s primarily as a response to the ecological changes in mountain lakes due to air pollution and missing data from the pre-industrial period as well as a need to quantify anthropic impact on the landscape. In the present paper, we reviewed 53 publications, including research papers, monographs, conference abstracts and theses, dealing with aquatic proxies in Holocene lake sediments to identify (1) the location of surveyed sites, (2) proxies used, and (3) the object of the paleolimnological reconstructions. The vast majority (37) of the analysed paleolimnological localities (51) took place in the High Tatra Mountains, focusing on the alpine lakes of glacial origin. The most frequently used biological proxy was Chironomidae remains (44%). In contrast, Cladocera, Ostracoda, loss-on-ignition, molluscs and stable isotopes were used only in 10–12% of studies. Most studies (84%) focused on a simple ecological reconstruction of the past environment, and only 24% of the studies attempted to reconstruct specific ecological variables, properties and processes, such as acidification (10%), temperature (8%) and eutrophication (4%). Only 2% of the studies used molecular techniques. Sixteen out of the 51 cores analysed (i.e., 31%) were dated by radiometric methods. In the end of our review we pinpoint the weaknesses of the local paleolimnological research and sketch possible future directions.

Key words: paleoproxies; Chironomidae; Cladocera; Diatoms; paleoecology; West Carpathians

Introduction

The Carpathian Region has for a long time been lacking good paleoenvironmental and especially paleolimnological records, particularly for the Late Quaternary. In the last decades, however, many new sedimentary sequences were obtained and studied using a wide range of paleoproxies (Buczkó et al. 2009).

The first lake sediment surveys in Slovakia were focusing on pollen and plant macrofossil analysis (Hüttemann & Bortenschlager 1987; Wacnik, 1995) and later more studies followed with that scope (e.g., Rybníčková & Rybníček 2006). However, paleolimnological research *sensu stricto* started in the end of the 1990s as a response to lake acidification and the lack of reliable data from the pre-acidification and pre-industrial period. These studies were part of a trans-European network (AL:PE, MOLAR, EMERGE) aiming to reconstruct complex physicochemical factors and aquatic communities of mountain lakes from Scandinavia to the Iberian Peninsula. Therefore, it is not surprising that the first paleolimnological studies in Slovakia were focusing on lakes in the High Tatra Mountains (Mts) as the region potentially most impacted by acidification and in general extremely sensitive to environmental changes. The first sedimentary records were obtained from a heavily acidified lake (Bitušík 1994: Starolesnianske pleso) and a non-acidified lake (Bitušík & Kubovčík 1999a, b: Nižné Terianske pleso) and were followed by other High Tatra lakes. In fact, the national paleolimnological research was for a long time predominantly dedicated to high altitude lakes. Several studies (Agustí-Panareda & Thomson 2002; Battarbee et al. 2002a, b; Catalan et al. 2002; Appleby & Piliposian 2006) resulted from the above mentioned joint European projects studying remote mountain lakes as sentinels of environmental changes throughout Europe (for detailed description of long-term ecological research in the Tatra Mts see Štefková & Šporka 2001).

Only few localities have been investigated outside the Tatra Mts, mostly "paleo-lakes", i.e., former lakes that existed in the past when hydrological conditions were different and since they dried out and become terrestrial systems (Pišút et al. 2010; Pařil & Petr 2011; Pařil & Břečková 2013; Petr et al. 2013) or paleomean-

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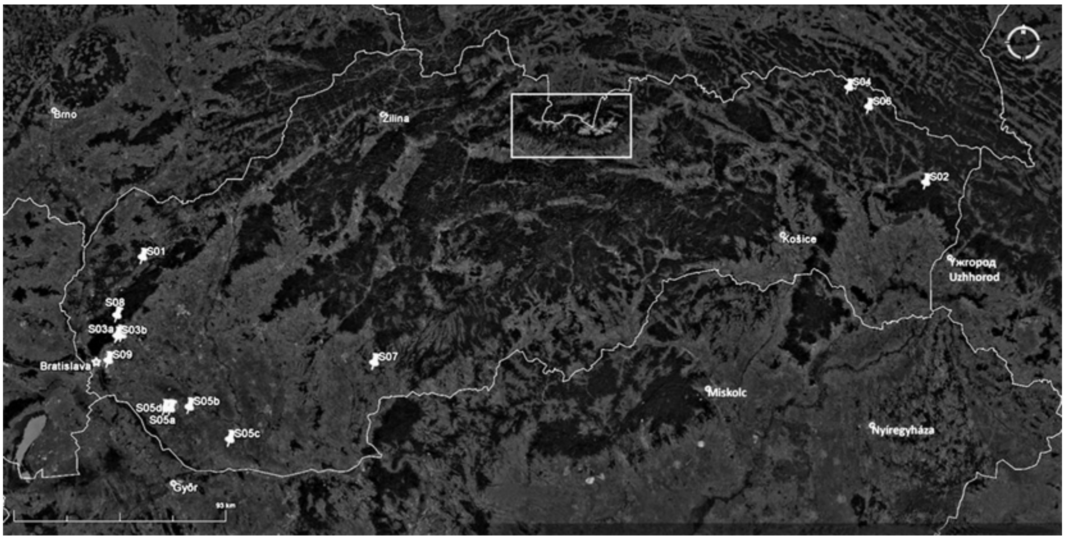

Fig. 1. Studied recent- and paleo-lakes in the territory of Slovakia (for codes see Table 1). White rectangle indicates the Tatra Mountains (shown in Fig. 2 in detail).

ders of large rivers (Pišút & Čejka 2002; 2005; Pišút et al. 2004; Pišút & Procházka 2012).

Two monographs were published focusing on the paleolimnological reconstructions of acidification and climate change in the High Tatra Mts (Kubovčík 2012) and on chironomids as paleoindicators of environmental changes and their use in paleolimnological reconstructions (Kubovčík 2013).

In addition to standard research papers and monographs, a significant part of the Slovakian paleolimnological research has only been published as "grey literature", i.e., as theses (Štefková 2003; Poláková 2006; Némethová 2008; Blechová 2014; Potůčková 2014) or abstracts (Pařil & Petr 2011; Pařil & Břečková 2013).

Since paleolimnological research has become more extensive over the last years in Slovakia, our goal with the present paper is to provide a review of the indigenous paleolimnological research of Holocene timescale. We addressed the following questions: (1) which geographic areas were the most surveyed, (2) what proxies have been the most used, (3) what was the most frequent object of the paleolimnological reconstructions, and (4) what is the time scale of the studies using lake sediments in Slovakia? We think that the answers can help to identify the strength and weaknesses of the national paleolimnological research and to indicate its potential future directions.

Methods

All available literature dealing with paleolimnological reconstruction based on sediments of Slovakian lakes was collected and analysed including research papers, monographs, bachelor-, master- and PhD-theses, as well as conference abstracts. Duplicate and partial studies were not included, i.e., if the sediment sequence was published as a conference paper and later as a publication in a peer-reviewed journal, only the latter was taken into account. Moreover, only those studies were included to the analysis that fulfilled the following criteria:

1. Holocene time scale – the studies should have operated within the Late Quaternary and recent time scale;
2. Lake sediment core – the sedimentary record included in this study must be lake sediment, either recent- or paleo-lake. In paleo-lake studies only aquatic proxies were taken into account;
3. "Aquatic" proxies – only studies using at least one aquatic biological proxy, i.e. remains of aquatic organisms (both animals, e.g., chironomids, cladocerans, ostracods, or plants, e.g., diatoms, plant-macrofossils) were taken into account;
4. Non-pollen proxies – studies including only pollen were excluded from analysis.

Results and discussion

Location of sites

In total, 53 paleolimnological studies (from 51 sites) investigating Late Pleistocene and Holocene timescales of lake sediments situated in the entire territory of Slovakia were analysed (Figs 1, 2, Table 1). This number is considerably higher than the 15 Slovakian studies discussed in a review summarizing paleolimnology in the Carpathians (Buczkó et al. 2009). The reason for it, except for the time lag between the publications, is that Buczkó et al. (2009) included only studies with dated sediment records. Strikingly, however, the number of studies using dated sediments is currently very close to that previously stated in Buczkó et al. (2009) demonstrating low progress and a strong need for using radiometric methods in order to put the reconstructed events into a reliable timeframe.

About 13% of the studies used in our review were bachelor-, master- or PhD-thesis written in Slovak or Czech, thus representing "grey literature". We included these sources to our review because they can be valuable for the local paleolimnological community, especially if the research has not been published elsewhere.

About 75% of the studies are located in the High Tatra Mts (Fig. 2). The remaining 25% are dealing

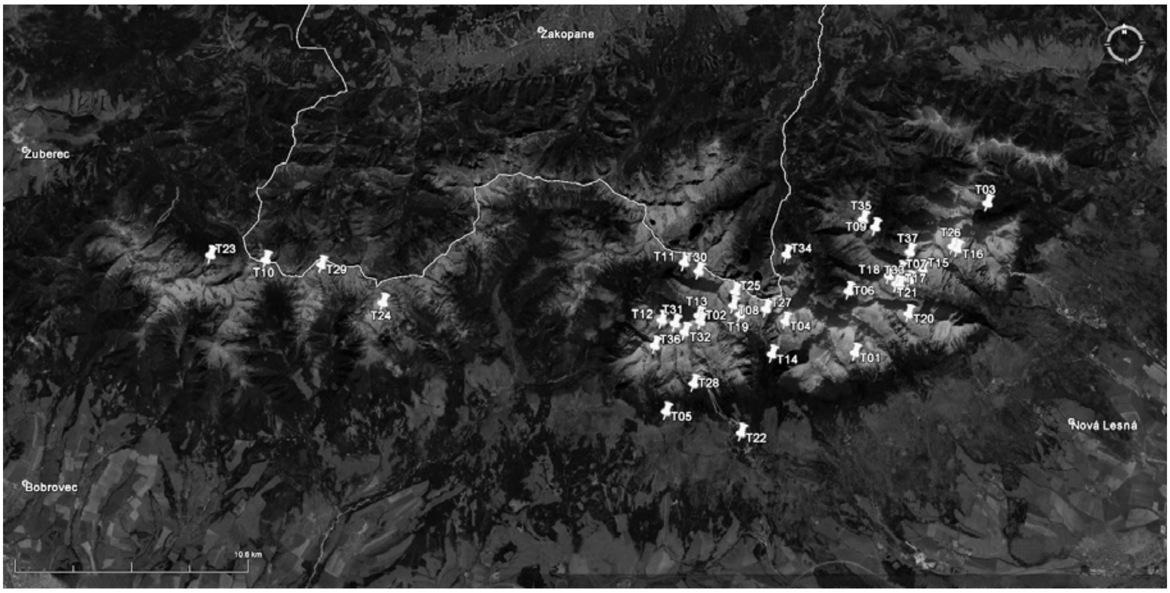

Fig. 2. Lakes in the Tatra Mountains with studied paleolimnological records.

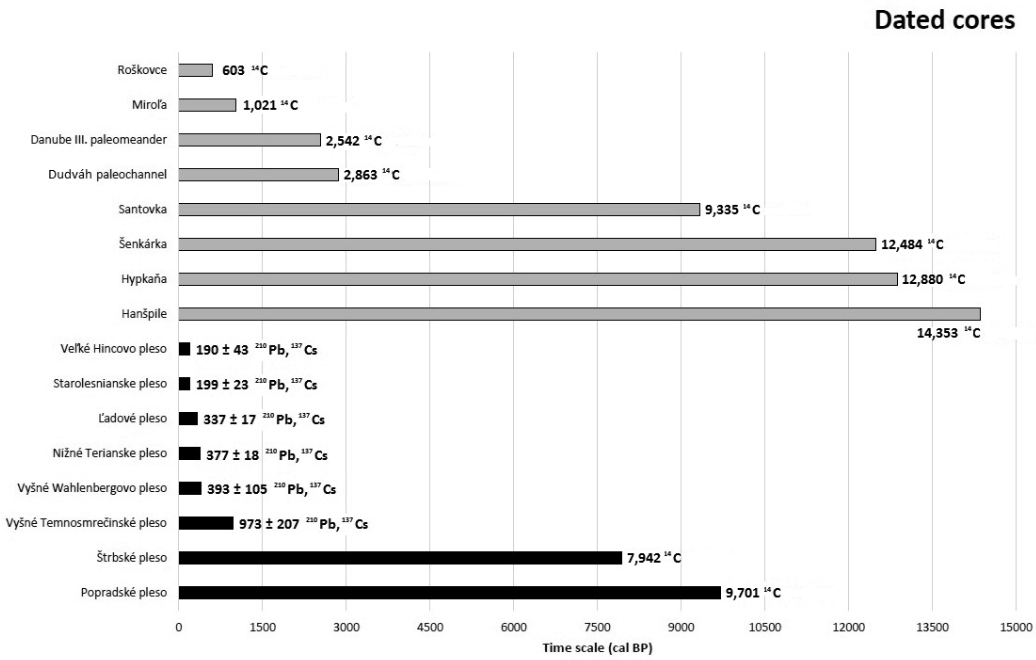

Fig. 3. Dated limnic deposits from Slovakia and used radiometric methods. Radiocarbon dates refer to median age (for data source see Table 1).

with river systems (paleo-meanders) and peat bogs, situated mainly in the Slovakian lowland (Fig. 1). The central position of the High Tatra lakes in the Slovak paleolimnological research is not surprising: owing to the high sensitivity of the mountain regions to climate variations, high number of lakes and peat bogs, and the remote and thus usually natural character of the mountain environment, the Tatra Mts belong to the best sites for Holocene paleoclimate surveys in central Europe (Gasiorowski & Sienkiewicz 2010).

The most frequently analysed sites in the High Tatra Mts used for paleolimnological investigations were (in order of decreasing frequency) lakes Nižné Terianske pleso, Starolesnianske pleso, Ľadové pleso, Vyšné Temnosmrečinské pleso and Vyšné Wahlenbergovo pleso (Šporka et al. 2002; Kubovčík & Bitušík 2006; Bitušík et al. 2009). One of the most extensively studied lakes in the Western Carpathians is lake Nižné Terianske pleso, from which as much as eight proxies were analysed and interpreted in multiple papers (e.g., Šporka et al. 2002; Appleby & Piliposian 2006; Marková et al. 2006; Bitušík et al. 2009). Out of the Tatra Mts, most of the paleolimnological studies were focusing on the reconstruction of paleolakes (e.g., Buczkó et al. 2009; Pišút el al. 2010; Pařil & Břečková 2013; Petr et al. 2013). For the complete list of papers conducted at each site, see Table 1.

Table 1. Lakes and paleo-lakes in Slovakia with studied paleolimnological record, their coding, geographic coordinates, analysed proxies, applications and references. Dated sediment sequences are marked with asterisk.

Code	Site	Coordinates	Altitude (m a.s.l.)	Core length (cm)	Proxies	Application	Lake type	References
T01	Batizovské pleso	49°9′6.94″N, 20°7′48.97″E	1890	15–17	cladocerans, diatoms, isotopes	acidification, ecology	recent	Kopáček et al. (2004), Sacherová et al. (2006), Štefková (2009)
T02	Capie pleso	49°10′5.34″N, 20°2′10.64″E	2072	15–17	cladocerans, diatoms	acidification, ecology	recent	Sacherová et al. (2006), Štefková (2009)
T03	Čierne Kežmarské pleso	49°12′36.11″N, 20°13′18.29″E	1552	15–17	cladocerans, diatoms	acidification, ecology	recent	Sacherová et al. (2006), Štefková (2009)
T04	Dračie pleso	49°9′58.64″N, 20°5′17.26″E	2024	–	cladocerans, isotopes	acidification, ecology	recent	Kopáček et al. (2004), Sacherová et al. (2006)
T05	Jamské pleso	49°7′58.85″N, 20°0′44.80″E	1454	–	isotopes	acidification, eutrophication	recent	Kopáček et al. (2006b)
T06	Litvorové pleso	49°10′37.20″N, 20°7′44.83″E	1863	–	cladocerans, isotopes	acidification, ecology	recent	Kopáček et al. (2004), Sacherová et al. (2006)
T07	Ľadové pleso*	49°11′2.65″N, 20°9′41.01″E	2057	33	isotopes, diatoms, cladocerans, chironomids	acidification, ecology, eutrophication, molecular analysis	recent	Kubovčík et al. (2003), Kopáček et al. (2004, 2006a), Kubovčík & Fečkaninová (2004), Kubovčík (2006, 2012, 2013), Kubovčík & Bitušík (2006), Kubovčík & Beták (2004), Marková et al. (2006), Sacherová et al. (2006), Appleby & Piliposian (2006), Štefková (2009)
T08	Malé Hincovo pleso	49°10′25.96″N, 20°3′25.89″E	1923	–	isotopes, cladocerans	acidification, ecology	recent	Kopáček et al. (2004), Sacherová et al. (2006)
T09	Malé Žabie Javorové pleso	49°12′9.06″N, 20°8′58.05″E	1713	–	cladocerans	acidification, ecology	recent	Sacherová et al. (2006)
T10	Nižné Jamnícke pleso	49°12′10.66″N, 19°46′12.32″E	1737	15–17	isotopes, diatoms, cladocerans	acidification, ecology	recent	Kopáček et al. (2004), Sacherová et al. (2006), Štefková (2009)
T11	Nižné Temnosmrečinské pleso	49°11′33.20″N, 20°1′45.22″E	1674	21	isotopes, diatoms, cladocerans	acidification, molecular analysis	recent	Kopáček et al. (2004), Marková et al. (2006), Štefková (2009)
T12	Nižné Terianske pleso*	49°10′10.29″N, 20°0′46.02″E	1941	35	isotopes, diatoms, cladocerans, chironomids, molluscs, LOI	acidification, ecology, eutrophication, temperature reconstruction, molecular analysis	recent	Augustí-Panareda & Thomson (2002), Bitušík & Kubovčík (1999a,b), Battarbee et al. (2002a,b), Appleby & Piliposian (2006), Catalan et al. (2002), Šporka et al. (2002), Štefková (2001, 2003), Kopáček et al. (2004, 2006a), Marková et al. (2006), Sacherová et al. (2006), Bitušík et al. (2009), Kubovčík (2013)
T13	Okrúhle pleso	49°10′13.83″N, 20°2′7.32″E	2114	–	cladocerans, diatoms	acidification, ecology	recent	Sacherová et al. (2006)
T14	Popradské pleso*	49°9′12.43″N, 20°4′47.46″E	1494	334	macrofossils, chironomids, diatoms, cladocerans	ecology	recent	Rybníčková & Rybníček (2006), Dobríková et al. (2014, 2016), Hamerlík et al. (2016)
T15	Prostredné Sivé pleso	49°11′2.67″N, 20°10′31.01″E	2022	15–17	cladocerans, diatoms	acidification, ecology	recent	Sacherová et al. (2006), Štefková (2009)
T16	Prostredné Spišské pleso	49°11′28.92″N, 20°11′52.26″E	2010	–	cladocerans	acidification, ecology	recent	Sacherová et al. (2006)

Table 1. (continued)

Code	Site	Coordinates	Altitude (m a.s.l.)	Core length (cm)	Proxies	Application	Lake type	References
T17	Prostredné Zbojnícke pleso	49°10′42.03″N, 20°9′38.01″E	1967	15–17	cladocerans, diatoms	acidification, ecology	recent	Sacherová et al. (2006), Štefková (2009)
T18	Pusté pleso	49°10′55.52″N, 20°9′14.02″E	2063	15–17	cladocerans, diatoms	acidification, ecology	recent	Sacherová et al. (2006), Štefková (2009)
T19	Satanie pleso	49°10′12.55″N, 20°3′39.87″E	1900	–	isotopes, cladocerans	acidification, ecology	recent	Kopáček et al. (2004), Sacherová et al. (2006)
T20	Slavkovské pleso	49°9′58.97″N, 20°9′49.37″E	2034	17	cladocerans, diatoms	acidification, ecology	recent	Sacherová et al. (2006), Štefková (2009)
T21	Starolesnianske pleso*	49°10′48.31″N, 20°9′59.87″E	1986	19	isotopes, diatoms, cladocerans, chironomids	acidification, ecology, eutrophication	recent	Appleby & Piliposian (2006), Bitušík (1994, 2002), Stuchlík et al. (2001), Kopáček et al. (2004, 2006a), Kubovčík & Bitušík (2006), Blechová (2014), Sacherová et al. (2006), Štefková (2009), Svitok et al. (2012), Kubovčík (2013)
T22	Štrbské pleso*	49°7′21.92″N, 20°3′27.60″E	1346	395	cladocerans, macrofossils	ecology, molecular analyses	recent	Stasiak (1984), Rybníčková & Rybníček (2006), Hamrová et al. (2010)
T23	Štvrté Roháčske pleso	49°12′21.88″N, 19°44′9.04″E	1718	15–17	diatoms, cladocerans	acidification, ecology	recent	Kopáček et al. (2004), Štefková (2009), Sacherová et al. (2006)
T24	Veľké Bystré pleso	49°10′58.03″N, 19°50′31.98″E	1892	–	cladocerans	acidification, ecology	recent	Kopáček et al. (2004), Sacherová et al. (2006)
T25	Veľké Hincovo pleso*	49°10′45.40″N, 20°3′32.27″E	1946	29	isotopes, diatoms, cladocerans	acidification, ecology, eutrophication	recent	Kopáček et al. (2004, 2006a,b), Poláková (2006), Sacherová et al. (2006) Appleby & Piliposian (2006), Kubovčík (2006), Poláková & Štefková (2006), Štefková (2009), Kubovčík (2012, 2013)
T26	Veľké Spišské pleso	49°11′33.13″N, 20°11′41.31″E	2014	15–17	isotopes, diatoms, cladocerans	acidification, ecology	recent	Kopáček et al. (2004), Sacherová et al. (2006), Štefková (2009)
T27	Veľké Žabie pleso	49°10′18.28″N, 20°4′38.09″E	1919	15–17	isotopes, diatoms, cladocerans	acidification, ecology	recent	Kopáček et al. (2004), Sacherová et al. (2006), Štefková (2009)
T28	Vyšné Furkotské pleso	49°8′36.76″N, 20°1′47.90″E	1712	–	cladocerans	acidification, ecology	recent	Sacherová et al. (2006)
T29	Vyšné Račkove pleso	49°11′59.17″N, 19°48′16.09″E	1697	15–17	isotopes, diatoms	acidification	recent	Kopáček et al. (2004), Štefková (2009)
T30	Vyšné Temnosmrečinské pleso*	49°11′19.42″N, 20°2′16.01″E	1716	30	isotopes, LOI, diatoms, cladocerans, chironomids	acidification, ecology, molecular analysis	recent	Kopáček et al. (2004), Poláková (2006), Sacherová et al. (2006), Poláková & Štefková (2006), Appleby & Piliposian (2006), Marková et al. (2006), Némethová (2008), Bitušík et al. (2009), Štefková (2009), Kubovčík (2012, 2013)
T31	Vyšné Terianske pleso	49°10′4.26″N, 20°1′13.92″E	2109	–	isotopes, cladocerans	acidification, ecology	recent	Kopáček et al. (2004), Sacherová et al. (2006)

Table 1. (continued)

Code	Site	Coordinates	Allti- tude (m a.s.l.)	Core length (cm)	Proxies	Application	Lake type	References
T32	Vyšné Wahlen-bergovo pleso*	49°9′51.13″N, 20°1′33.91″E	2145	35	isotopes, LOI, diatoms, cladocerans, chironomids	acidification, ecology	recent	Kopáček et al., (2001), Kubovčík & Beták (2004), Appleby & Piliposian (2006), Kubovčík & Bitušík (2006), Sacherová et al. (2006), Poláková & Štefková (2006), Poláková (2006), Kubovčík et al. (2007), Némethová (2008), Bitušík et al. (2009), Štefková (2009), Kubovčík (2012, 2013)
T33	Vyšné Zbojnícke pleso	49°10′43.39″N, 20°9′30.30″E	1975	15–17	cladocerans, diatoms	acidification, ecology	recent	Sacherová et al. (2006), Štefková (2009)
T34	Vyšné Žabie Bielovodské pleso	49°11′36.57″N, 20°5′34.32″E	1700	15–17	cladocerans, diatoms	acidification, ecology	recent	Sacherová et al. (2006), Štefková (2009)
T35	Zelené Javorové pleso	49°12′20.96″N, 20°8′30.73″E	1816	–	cladocerans	acidification, ecology	recent	Sacherová et al. (2006)
T36	Zelené Krivánske pleso	49°9′34.33″N, 20°0′26.96″E	2017	15–17	isotopes, diatoms, cladocerans	acidification, ecology	recent	Kopáček et al. (2004), Štefková (2009), Sacherová et al. (2006)
T37	Žabie Javorové pleso	49°11′28.89″N, 20°10′7.33″E	1886	15–17	isotopes, diatoms, cladocerans	acidification, ecology	recent	Kopáček et al. (2004), Sacherová et al. (2006), Štefková (2009)
S01	Hanšpile*	48°33′14.28″N, 17°18′2.54″E	191	104	macrofossils, molluscs, LOI	ecology, eutrophication	paleo	Hájková et al. (2015)
S02	Hypkaňa*	48°54′47.21″N, 22°9′49.50″E	848	1110	macrofossils, chironomids	ecology, temperature reconstruction	paleo	Hájková et al. (2016), Pařil & Břečková (2013)
S03a	Jurský Šúr	48°13′58.15″N, 17°14′1.84″E	131	245	macrofossils, chironomids, diatoms, LOI	ecology	paleo	Pařil & Petr (2011)
S03b	Šúr	48°13′40.90″N, 17°12′18.17″E	134	245	macrofossils	ecology	paleo	Petr (2013), Petr et al. (2013)
S03c	Šúr profile	48°14′13.45″N, 17°12′57.31″E	128	300	macrofossils, LOI, isotopes	ecology	paleo	Potůčková (2014)
S04	Miroľa*	49°19′59.05″N, 21°43′37.01″E	413	80	macrofossils, molluscs	ecology	paleo	Jamrichová et al. (2014)
S05a	Danube I. paleochannel	47°56′51.55″N, 17°32′29.61″E	117	70	macrofossils, molluscs	ecology	paleo	Pišút & Čejka (2005)
S05b	Danube II. paleochannel	47°57′29.10″N, 17°41′15.89″E	110	390	macrofossils, molluscs	ecology	paleo	Pišút et al. (2004)
S05c	Dudváh paleochannel*	47°50′19.64″N, 17°56′48.64″E	107	130	plant-macrofossils, molluscs, ostracodes	ecology	paleo	Pišút et al. (2010)
S05d	Danube III. paleomeander*	47°56′54.08″N, 17°34′39.01″E	112	280	macrofossils	ecology	paleo	Pišút & Procházka (2012)
S06	Roškovce*	49°14′46.91″N, 21°50′48.87″E	378	73	macrofossils, molluscs	ecology	paleo	Jamrichová et al. (2014)
S07	Santovka*	48°9′25.58″N, 18°45′59.62″E	142	385	macrofossils, chironomids	ecology	paleo	Petr (2013)
S08	Šenkárka*	48°18′38.78″N, 17°11′21.26″E	510	106	macrofossils, chironomids	ecology	paleo	Gálová et al. (2016)
S09	Vlčie hrdlo	48°7′40.49″N, 17°10′12.06″E	136	120	molluscs	ecology	recent	Pišút & Čejka (2002)

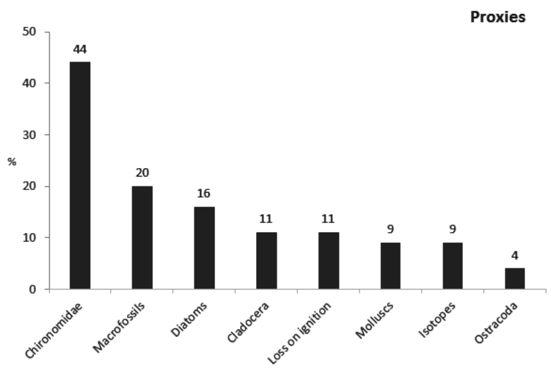

Fig. 4. Proportion of the used proxies in all paleolimnological studies from Slovakia.

Timescale of the paleoreconstructions

In our review, 16 studies using dated sediment cores were recorded (Fig. 3). Eight dated sediment cores come from recent lakes in the High Tatra Mts, and eight from paleo-lakes situated mainly in the lowland region of western Slovakia. In most cases, ^{14}C, ^{210}Pb and ^{137}Cs dating methods were used, however, sediments of two recent lakes (lakes Popradské pleso and Štrbské pleso) were dated by pollen associations (Rybníček & Rybníčková 2006), similarly to paleo-lake cores.

Sediment cores from recent lakes represent 72% of all investigated cores (including not dated), the remaining 28% come from paleo-lakes. The oldest paleo-lake sediment sequence obtained from Hanšpile is dated back to 14,661–14,140 cal y BP (median 14,353 cal y BP). Recent lake sediments represent shorter periods: the oldest dated sequence using absolute dating methods, i.e., radioisotopes (from lake Vyšné Temnosmrečinské pleso) is about 1,044 years old (973 ± 207 AD, Kopáček et al. 2004).

Used paleo-proxies

The most frequently used proxy was Chironomidae (44%) followed by macrofossil remains (20%) (Fig. 4). The sum of percentage of proxies is higher than 100%, because some studies used a multi-proxy approach and thus the same study can be counted several times. Surprisingly, loss-on-ignition was only poorly applied in the studies (12%), even though it is a proxy that is easy to analyse and has high interpretation value. The same applies for cladocerans and diatoms. Percentage share of these proxies in the analysed studies is 12% (cladocerans) and 16% (diatoms), which might look like a relatively high number, however, they were employed only in three and four studies, respectively. This discrepancy is caused by the overall low number of Slovakian paleolimnological studies. Even greater contradiction is visible when we consider the number of sites, where the proxies were applied: e.g., subfossil Cladocera were studied in 34 sites, however, the vast majority of the sites were included in one study only (Sacherová et al. 2006).

Non-biting midges (Chironomidae). The first paleolimnological studies using Chironomidae in Slovakia were published in the 1990s within the framework of trans-European projects such as MOLAR and EMERGE (Bitušík 1994; Bitušík & Kubovčík 1999a, b; Šporka et al. 2002) from Starolesnianske pleso and Nižné Terianske pleso, High Tatra Mts. Chironomidae were used to reconstruct long-term changes of the acidified Starolesnianske pleso (Stuchlík et al. 2001) and non-acidified lakes, such as Ľadové pleso (Kubovčík & Fečkaninová 2004; Kubovčík 2006), Vyšné Temnosmrečinské pleso (Kubovčík & Beták 2004) and Veľké Hincovo pleso (Kubovčík 2006). Kubovčík & Bitušík (2006) reconstructed the recent history of three High Tatra lakes to compare community changes caused by different degree of acidification from no change to strong decrease in pH. Bitušík et al. (2009) used multi-proxy approach (chironomids along with diatoms and loss on ignition) to reconstruct the environmental conditions of three remote Tatra lakes over the last 500 to 1,000 years. Hamerlík et al. (2016) analysed chironomid head capsules (along with loss-on-ignition and concentration of elements) form the sediment of lake Popradské pleso, High Tatra Mts, to track the response of aquatic biota to human disturbances in the lake catchment.

Diatoms (Bacillariophyceae). Diatoms were mainly used in studies focusing on quantitative reconstructions and descriptions of stratigraphic changes. Štefková (2001, 2009) compared diatom communities to reconstruct changes of pH in 22 High Tatra lakes. Šporka et al. (2002) used diatoms to reconstruct mean summer temperatures and Bitušík et al. (2009) to reconstruct Little Ice Age, air pollution and lake acidification in the past. Petr et al. (2013) studied environmental change and environmental development of a paleo-lake close to Šúr village, W Slovakia.

Water fleas (Cladocera). Analysis of subfossil Cladocera as a paleoproxy has not yet been given sufficient attention in Slovakia. Marková et al. (2006) studied physical conditions and abundance of *Daphnia pulicaria* Forbes, 1893 resting eggs in sediment cores from six mountain lakes in the High Tatra Mts. The authors concluded that age, low quantity and poor physical condition of resting eggs from the surveyed lake sediments were unsuitable for genetic analyses. In addition, due to their poor conditions, also the possibility of autogenous restoration of *Daphnia* populations from the resting egg banks in the Tatra lakes sediments is negligible. Sacherová et al. (2006) studied long-term changes of the littoral Cladocera of 46 Tatra lakes through a major acidification event. The only paleogenetic study from the High Tatra Mountain lakes (Hamrová et al. 2010) confirms that molecular methods are useful for studying the recent population structures of zooplankton species forming dormant egg banks. However, they lack reliably identifiable remains in sediments, and show that the extreme development of tail spines in mountain lake *Daphnia* is associated with yet unclear environmental factors rather than taxonomic status.

Object of paleoreconstructions

As much as 84% of all studies were focusing on general ecological reconstruction and description of the strati-

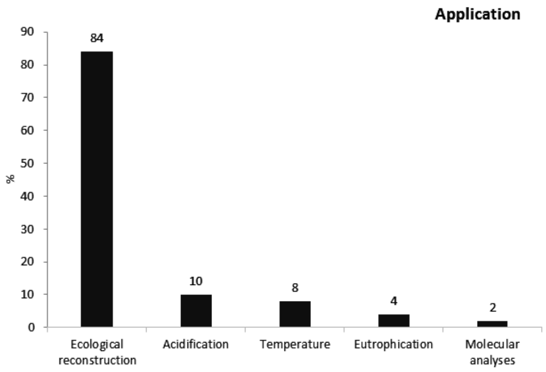

Fig. 5. Application of the used proxies in paleolimnological research from Slovakia.

graphic changes of the surveyed proxies (Fig. 5). Only few studies attempted to reconstruct specific quantitative variables, such as temperature changes (e.g., Augustí-Panareda & Thompson 2002; Battarbee et al. 2002a) or analyse acidification and eutrophication (Kopáček et al. 2004) but these approaches are poorly represented in the studies. There is only a single study using molecular (paleogenetic) methods for paleolimnological reconstruction in the High Tatra Mts (Hamrová et al. 2010).

Summary of the main results

Late Pleistocene to Holocene period. The oldest sequence from the Bölling/Alleröd Interstadial depicts the influence of the sandy bedrock on the analysed forest association in the west Slovakian lowland. Sandy dunes were stabilised by pine woodlands inside of which diverse and abundant wetland vegetation evolved with boreal and continental fen species (Hájková et al. 2015). The authors (op. cit.) point out the destruction of the wetlands by human activities and the disappearance of the relict species occurring in this region since the last Interstadial. In the hilly region of the same area, an Alleröd open pine-birch forest surrounding the oligotrophic to mesotrophic lake was replaced by a broadleaved forest during the early Holocene and enriched in *Fagus* no later than 5,800 cal y BP. The natural forest succession was disrupted by two fire events in the area (Gálová et al 2016).

The only publication trying to quantify the temperature changes in the Holocene (Hájková et al. 2016) reconstructs chironomid-inferred summer temperatures between 13,000 and 5,000 cal y BP from east Slovakia and state a temperature fluctuation from 7 to 15.5 ℃. According to the authors the warmest early Holocene period started between 14,400–8,850 cal y BP, i.e. earlier than in other parts of Europe, probably as the result of orographic effects.

The Holocene studies in the Danube lowland area aim to reconstruct evolution of the man influenced landscape changes. This is a case of the active thermal springs in Santovka, which attracted the Neolitic people, but his impact on the early Holocene lowland ecosystem was low due to low population and ecosystem resilience. Increased population densities, however, caused changes in the sedimentary record due to higher erosion of the loess in the surroundings (Petr 2015). The Subboreal and Subatlantic sedimentary successions of the Danube lowland meanders document a larger distribution of the endangered, rare and protected water plants in the past and a present-day habitat is a result of changes associated with draining, intensified agriculture, ruderalisation and the spread of invasive species (Pišút and Procházka 2012; Pišút et al. 2010).

The Holocene evolution of the alpine region is documented from lakes Popradské pleso and Štrbské pleso (Rybníček & Rybníčková 2006). The study (op. cit.) indicates mountain tundra in the late Glacial, coniferous forest since the early Holocene and geomorphological and edaphic control of the forest line.

Medieval to Modern period. Most of the dated Medieval to Modern sedimentary sequences (representing < 1,000 years, Fig. 3) come from recent lakes from the High Tatra Mts (Šporka et al. 2002 Kubovčík 2006; Kubovčík & Bitušík 2006; Bitušík et al. 2009; Hamerlík et al. 2016); only two originate from spring-fen sites situated in the Slovak Eastern Carpathians (Jamrichová et al. 2014). Jamrichová et al. (2014) concluded that human impact was the main factor of landscape transformation in the last millennium; due to deforestation, people directly created spring-fen ecosystems and by husbandry activities they influenced the species composition. The most remarkable changes involving water regime stabilization and undisturbed development of plants and molluscs took place after the human impact declined.

Trends in the Tatra Mts lake sediments indicated basically three major past environmental events: acidification, organic pollution and climatically driven changes. Most of the research in the Tatra Mts focused on the acidification of the Tatra lakes, since that was a major environmental issue of the region peaking during the second half of the 20th century. However, while some lakes suffered of severe acidification that caused significant changes in their biological communities (Kubovčík & Bitušík 2006), others were influenced only slightly or remained non-acidified (Kubovčík 2006; Kubovčík & Bitušík 2006). Lakes in lower altitudes were significantly influenced by direct human activities over the 20th century, such as construction activities and wastewater outflow from tourist facilities related to rapid growth of tourism (Hamerlík et al. 2016). Different paleo-indicators responded with different intensity and slightly different timing to human impact (Dobríková et al. 2016). Considerable fluctuation of rheophilic/rheobiontic taxa suggests climatically driven changes, such as periods of higher precipitation or lower temperatures. Both can result in the formation of a stronger, more stable inlet supplied from permanent granular snow fields in the lake basin or simply higher precipitation (Šporka et al. 2002; Hamerlík et al. 2016). Both Šporka et al. (2002) and Bitušík et al. (2009) found pronounced positive correlation between temperature and subfossil diatom communities it the sediment of some Tatra lakes.

Future perspectives

The review of paleolimnological research indicates large time- and spatial gap in our knowledge of the past natural changes in the territory of Slovakia and shows several predictions for the future:

1. Most of the studies were located in the High Tatra Mts. Even though the Tatra Mts represent an ideal spot for studying Holocene climate oscillations, there are many other recent- and paleo-lakes with high paleolimnological potential that have been neglected so far, such as naturally dammed lakes, oxbows and peatbogs of yet unknown age. In addition, study of manmade lakes situated in former mining regions could be of high importance. Owing to their artificial origin the age of these lakes is known and the way of usage is usually well documented. Thus, they could be used for high resolution studies on the influence of human activities on lake ecosystems and landscape changes.

2. Chironomidae were the most frequently used proxy used in the reconstructions. The reason for this is most likely historical, since chironomid research has a long tradition in the Slovak hydrobiological community. At the same time, there is a lack of specialists for other proxies (cladocerans, diatoms, phantom midges, mites, beetles, etc.). This can be cured either by broader international cooperation of scientists or educating a new generation of specialists.

3. Impact of Holocene climate oscillations in the territory of Slovakia. Effect and timing of short but severe events, such as the 8.2 ky cooling, the 4.2 ky aridification event or the Little Ice Age (LIA) are globally well mapped, however our knowledge of their impact on the biota and human population in our territory is very vague. The climatic phenomenon of LIA lasting from the 14^{th} to 19^{th} century influencing a modern European culture is identified in Central Europe (Kłapyta et al. 2016), however, there is very little information about the magnitude, variations and timing of it in Slovakia. Thus, future research should pay more attention to the identification and manifestation of these rapid climatic changes by finding relevant sedimentary records both in mountain and lowland areas. Moreover, the position of the sites along the borders of the country offers to study the west-east gradient of continentality within the Slovak territory.

4. Paleolimnological research in Slovakia has been mostly focusing on basic description, general stratigraphic succession and simple ecological reconstruction of the water environment. This is basic for every paleolimnological study, because every reconstruction should be confronted with the ecology behind the environmental changes. However, to get more up-to-date results, it is of key importance to focus on more specific environmental changes caused by anthropic influences, interactions between organisms, in community or between communities. Application of molecular and paleogenetic methods to the paleolimnological research will be a great challenge for the Slovakian paleolimnology.

Acknowledgements

The study was co-financed by projects VEGA 1/0664/15, VEGA 2/0056/15 and APVV-15-0292 'Deglaciation and postglacial climatic evolution recorded in the lake deposits of the High Tatra Mountains'. The projects was also funded by the National Science Centre, Poland, contract no. 2015/19/P/ST10/04048 and the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 665778. We are grateful to Mats Rundgren (Lund University, Sweden) for calibration of the radiometric ages, Peter Bitušík and Tímea Chamutiova (Matej Bel University) for commenting on the manuscript.

References

Appleby P.G. & Piliposian G.T. 2006. Radiometric dating of sediment records from mountain lakes in the Tatra Mountains. Biologia **61 (Suppl 18):** S51–S64. DOI: 10.2478/s11756-006-0119-4

Augustí-Panareda A. & Thompson R. 2002. Reconstructing air temperature at eleven remote alpine and arctic lakes in Europe from 1781 to 1997 AD. J. Paleolimnol. **28:** 7–23. DOI: 10.1023/A:1020363700397

Battarbee R.W., Grytnes J.A., Thompson R., Appleby P.G., Catalan J., Korhola A., Birks H.J.B., Heegaard E. & Lami A. 2002a. Comparing palaeolimnological and instrumental evidence of climate change for remote mountain lakes over the last 200 years. J. Paleolimnol. **28:** 161–179. DOI: 10.1023/A:1020384204940

Battarbee R.W., Thompson R., Catalan J., Grytnes J.A. & Birks H.J.B. 2002b. Climate variability and ecosystem dynamics of remote alpine and arctic lakes: the MOLAR project. J. Paleolimnol. **28:** 1–6. DOI: 10.1023/A:1020342316326

Bitušík P. 1994. A preliminary report of response of sub-fossil chironomids (Diptera, Chironomidae) in the Lake Staroles-nianske pleso (The High Tatra Mts., Slovakia) to acidification of lake water, pp. 29–33. In: Zborník referátov X. Limnol. konf., Stará Turá, 17–21 October 1994, Slovenská limnol. spoločnosť, Česká limnol. Spoločnosť, 265 pp.

Bitušík P. 2002. Subfosílne spoločenstvá pakomárov (Diptera: Chironomidae) v sedimentoch horských jazier ako doklad histórie znečisťovania ovzdušia [Subfossil chironomid communities in mountain lakes as indicators of the history of air pollution]. Oecol. Mont. **11:** 68–70.

Bitušík P. & Kubovčík V. 1999a. Sub-fossil chironomids (Diptera: Chironomidae) from the sediments of the Nižné Terianske pleso (High Tatra Mts., Slovakia). Dipterol. Bohemoslov. **9:** 11–20.

Bitušík P. & Kubovčík V. 1999b. Pokus o rekonštrukciu zmien prostredia na základe subfosílnych zvyškov lariev pakomárov (Diptera: Chironomidae) zo sedimentov horských jazier [An attempt to reconstruct environmental changes from mountain lake sediments using subfossil chironomids], pp. 323–327. In: Atmosféra 21. storočia, organizmy a ekosystémy: Zborník referátov z medzinárodnej vedeckej konferencie Bioklimatologické pracovné dni 1999, TU Zvolen, 7–9 September 1999, Zvolen. ISBN: 80-228-0840-7

Bitušík P., Kubovčík V., Štefková E., Appleby P.G. & Svitok M. 2009. Subfossil diatoms and chironomids along an altitudinal gradient in the High Tatra Mountain lakes: a multi-proxy record of past environmental trends. Hydrobiologia **631:** 65–85. DOI: 10.1007/s10750-009-9802-0

Blechová M. 2014. Paleoekologický výskum horských jezer v oblasti Karpat: revize současného stavu [Paleolimnological survey of mountain lakes in the Carpathians: review of the current status]. Bc. Thesis. Univerzita Karlova v Praze, 55 pp. https://is.cuni.cz/webapps/zzp/detail/146239

Buczkó K., Magyari E.K., Bitušík P. & Wacnik A. 2009. Review of dated Late Quaternary paleolimnological records in the

Carpathian Region, east-central Europe. Hydrobiologia **631:** 3–28. DOI: 10.1007/978-90-481-3387-1_2

Catalan J., Ventura M., Brancelj A., Granados I., Thies H., Nickus U., Korhola A., Lotter A.F., Barbieri A., Stuchlík E., Lien L., Bitušík P., Buchaca T., Camarero L., Goudsmit G. H., Kopáček J., Lemcke G., Livingstone D.M., Muller B., Rautio M., Šiško M., Sorvari S., Šporka F., Strunecký O. & Toro M. 2002. Seasonal ecosystem variability in remote mountain lakes: implications for detecting climatic signals in sediment records. J. Paleolimnol. **28:** 25–46. DOI: 10.1023/A:1020315817235

Dobríková D., Hamerlík L., Szarlowic K., Kubica B., Šporka F. & Bitušík P. 2014. Dvestoročná história Popradského plesa: predbežné výsledky paleolimnologickej štúdie jeho sedimentov [The history of lake Popradské pleso over the last 200 years: preliminary results of the paleolimnological study of its sediments], pp. 79–84. In: Midriak R. & Zaušková Ľ. (eds), Biosférické rezervácie na Slovensku X., Zborník referátov z 10. národnej konferencie o biosférických rezerváciách SR, 21–22 October 2014, Stará Lesná, Belianum, Banská Bystrica, 197 pp. ISBN: 9788055708461

Dobríková D., Sochuliaková L., Stoklasa J., Hamerlík L. & Bitušík P. 2016. Paleolimnologický výskum pre adaptívny manažment v ochrane prírody: prípadová štúdia Popradského plesa (Vysoké Tatry, Slovensko) [Paleolimnological survey for the adaptive management in conservation biology: a case study of Popradské pleso lake (High Tatra Mountains, Slovakia]. Quaest. Rer. Natur. **3:** 24–41.

Gálová A., Hájková P., Čierniková M., Petr L., Hájek M., Novák J., Rohovec J. & Jamrichová E. 2016. Origin of a boreal birch bog woodland and landscape development on a warm low mountain summit at the Carpathian-Pannonian interface. Holocene **26:** 1112–1125. DOI: 10.1177/0959683616632884

Gasiorowski M. & Sienkiewicz E. 2010. The Little Ice Age recorded in sediments of a small dystrophic mountain lake in southern Poland. J. Paleolimnol. **43:** 475–487. DOI: 10.1007/s10933-009-9344-5

Hájková P., Pařil P., Petr L., Chattová B., Grygář T. & Heiri O. 2016. A first chironomid-based summer temperature reconstruction (13–5 ka BP) around 49° N in inland Europe compared with local lake development. Quat. Sci. Rev. **141:** 94–111. DOI: 10.1016/j.quascirev.2016.04.001.

Hájková M., Petr L., Horsák M., Rohovec J. & Hájek M. 2015. Interstadial inland dune slacks in south-west Slovakia: a multi-proxy vegetation and landscape reconstruction. Quat. Int. **357**: 314–328. DOI: 10.1016/j.quaint.2014.09.016

Hamerlík L., Dobríková D., Szarlowicz K., Reczynski W., Kubica B., Šporka F. & Bitušík P. 2016. Lake biota response to human impact and local climate during the last 200 years: A multi-proxy study of a subalpine lake (Tatra Mountains, W Carpathians). Sci. Total Environ. **545–546:** 320–328. DOI: 10.1016/j.scitotenv.2015.12.049.

Hamrová E., Goliáš V. & Petrusek A. 2010. Identifying century-old long-spined Daphnia: species replacement in a mountain lake characterised by paleogenetic methods. Hydrobiologia **643:** 97–106. DOI: 10.1007/s10750-010-0127-9

Hüttemann H. & Bortenschlanger S. 1987. Beiträge zur Vegetationsgeschichte Tirols VI: Riesengebirge, Hohe Tatra – Zillertal, Kühtai. Ber. Naturwiss.-Med. Verein Innsbruck **74:** 81–112.

Jamrichová E., Hájková P., Horsák M., Rybníčková E., Lacina A. & Hájek M. 2014. Landscape history, calcareous fen development and historical events in the Slovak Eastern Carpathians. Veget. Hist. Archaeobot. **23:** 497–513. DOI: 10.1007/s00334-013-0416-0

Kłapyta P., Zasadni J., Pociask-Karteczka J., Gajda A. & Franczak P. 2016. Late Glacial and Holocene paleoenvironmental records in the Tatra Mountains, East-Central Europe, based on lake, peat bog and colluvial sedimentary data: A summary review. Quat. Int. **415:** 126–144 DOI: 10.1016/j.quaint.2015.10.049

Kopáček J., Borovec J., Hejzlar J. Kotorová I., Stuchlík E. & Veselý J. 2006a. Chemical composition of modern and pre-acidification sediments in the Tatra Mountain lakes. Biologia **61 (Suppl 18):** S65–S76. DOI: 10.2478/s11756-006-0120-y

Kopáček J., Hardekopf D., Majer V., Pšenáková P., Stuchlík E. & Veselý J. 2004. Response of alpine lakes and soils to changes in acid deposition: the MAGIC model applied to the Tatra Mountain region, Slovakia-Poland. J. Limnol. **63:** 143–156. DOI: 10.4081/jlimnol.2004.143

Kopáček J., Stuchlík E. & Hardekopf D. 2006b. Chemical composition of the Tatra Mountain lakes: Recovery from acidification. Biologia **61 (Suppl. 18):** S21– S 33. DOI: 10.2478/s11756-006-0117-6

Kopáček J., Veselý J. & Stuchlík E. 2001: Sulphur and nitrogen fluxes and budgets in the Bohemian Forest and Tatra Mountains during the Industrial Revolution (1850–2000). Hydrol. Earth Syst. Sci. **5:** 391–405. DOI: 10.5194/hess-5-391-2001

Kubovčík V. 2006. The environmental history of two non-acidified alpine lakes (the High Tatra Mts., Slovakia) for the last c. 200 years: a palaeoecological study. Acta Univ. Carol. Biol. **50:** 73–84.

Kubovčík V. 2012. Paleoekológia tatranských jazier: pakomárovité (Diptera: Chironomidae), klimatické zmeny a acidifikácia [Paleoecology of the Tatra lakes: Chironomids (Diptera: Chironomidae), climate changes and acidification]. Vydavateľstvo Technickej univerzity vo Zvolene, Zvolen, 96 pp. ISBN: 9788022823661

Kubovčík V. 2013. Subfosílne spoločenstvá pakomárovitých (Diptera: Chironomidae) ako indikátory historických zmien prostredia [Subfossil chironomid communities (Diptera: Chironomidae) as indicators of historical environmental changes]. Vydavateľstvo Technickej univerzity vo Zvolene, Zvolen, 76 pp. ISBN: 9788022825801

Kubovčík V. & Beták M. 2004. Ninety years of environmental changes in Lake Vyšné Temnosmrečinské pleso (the High Tatra Mts., Slovakia) inferred from chironomids records (Diptera, Chironomidae), pp. 85–92. In: Bitušík P. (ed.), Dipterologica Bohemoslovaca **12**, Acta Facultatis Ecologiae (Zvolen) **12 (Suppl. 1).**

Kubovčík V., Beták M. & Fečkaninová G. 2003. Subfosilná fauna pakomárov (Diptera: Chironomidae) Ľadového plesa (Vysoké Tatry, Slovensko) [Subfossil chironomid communities (Diptera: Chironomidae) of Ľadove pleso lake (High Tatra Mts., Slovakia)], pp. 201–203. In: Bitušík P. & Novikmec M. (eds), Proc. 13th Conference of Slovak Limnol. Soc. & Czech Limnol. Soc., Banská Štiavnica, 23–27 June 2003, Acta Fac. Ecol. Zvolen **10 (Suppl. 1),** 323 pp.

Kubovčík V. & Bitušík P. 2006. Subfossil chironomids (Diptera, Chironomidae) in three Tatra Mountain lakes (Slovakia) on an acidification gradient. Biologia **61 (Suppl. 18):** S213–S220. DOI: 10.2478/s11756-006-0133-6

Kubovčík V. & Fečkaninová G. 2004. Subfossil chironomids (Diptera: Chironomidae) from the sediments of the Ľadové pleso lake (High Tatra Mts., Slovakia). Dipterol. Bohemoslov. 11, Folia Fac. Sci. nat. Univ. Masaryk. Brun. Biol. **109:** 173–182.

Kubovčík V., Némethová M. & Svitok M. 2007. 350-letnia historia Ochotkowatych (Diptera: Chironomidae) w alpejskim jeziorze Vyšné Wahlenbergovo pleso [350-years history of chironomids (Diptera: Chironomidae) in an alpine lake Vyšné Wahlenbergovo pleso]. Dipteron **23:** 50–52.

Marková S., Černý M., Rees D.J. & Stuchlík E. 2006. Are they still viable? Physical conditions and abundance of *Daphnia pulicaria* resting eggs in sediment cores from lakes in the Tatra Mountains. Biologia **61 (Suppl 18):** S135–S146. DOI: 10.2478/s11756-006-0126-5

Némethová M. 2008. Paleoekologická rekonštrukcia vývoja vybraných tatranských plies na základe analýzy zvyškov lariev pakomárov (Diptera: Chironomidae) [Paleoecological reconstruction of the development of selected Tatra Mts. lakes using subfossil chironomid remains]. MSc. Thesis, Technická univerzita vo Zvolene, Zvolen, 49 pp.

Pařil P. & Břečková V. 2013. Paleoreconstruction of ecological changes in filled up lake using subfossil chironomids – preliminary results from the Vihorlat Mts, Slovakia. In: 12th Workshop on Subfossil Chironomidae, New Forest, UK, 10–13 June 2013.

Pařil P. & Petr L. 2011. Subfossil chironomid head capsules of filled up shallow lake Jurský Šúr near Bratislava, Slovakia –

preliminary results. 10th Workshop on Subfossil Chironomidae, Finse, Norway, 30 June – 2 July 2011.
Petr L. 2015. Paleolimnologické lokality Západních Karpat a jejich význam pro rekonstrukci životního prostředí pozdního glaciálu a holocénu [Paleolimnological localities in the Western Carpathians and their importance for the reconstruction of the Late Glacial and Holocene environment]. Zprávy Čes. Bot. Společ. **50:** 247–265.
Petr L., Žáčková P., Grygar T. M., Píšková A., Křížek M., & Treml V. 2013. Šúr, a former late-glacial and Holocene lake at the westernmost margin of the Carpathians. Preslia **85:** 239–263.
Pišút P., Břízová E., Čejka T. & Pipík R. 2010. Paleofloristic and paleofaunistic analysis of Dudváh River oxbow and implication for Late Holocene paleoenvironmental development of the Žitný ostrov Island (SW Slovakia). Geol. Carpath. **61:** 513–533. DOI: 10.2478/v10096-010-0032-1
Pišút P. & Čejka, T. 2002. Historical development of floodplain site using Mollusca and Cartographic evidence. Ekológia **21 (4):** 378–396.
Pišút P. & Čejka T. 2005. Výsledky analýzy časti výplne zaniknutého ramena Dunaja na Žitnom ostrove (príspevok k historickému rozšíreniu niektorých mokraďových druhov) [Preliminary results of the analysis of a Danube paleomeander infill in Žitny ostrov Island – contribution to the knowledge on the historical distribution of some wetland species], pp. 278–286. In: Měkotová J. & Štěrba O. (eds), Sborník konference Říční krajina 3. Univerzita Palackého, 5–6 October 2005, Olomouc, 396 pp. ISBN: 80-244-1162-8
Pišút P., Kubalová S., Hajnalová M. & Slamková M. 2004. Study of the Danube River Palaeochannel, Slovakia (Preliminary results). Geomorph. Slov. **1:** 12–21.
Pišút P. & Procházka J. 2012. Výsledky analýzy rastlinných makrozvyškov z výplne paleomeandra Dunaja pri obci Vrakúň (Žitný ostrov) [Results of plant macrofossil analysis of the infill of a Danube paleomeander near Vrakúň village]. Bull. Slov. Bot. Spoloč. **1:** 87–101.
Poláková L. 2006. Rozsievky vybraných tatranských plies [Diatoms of selected Tatra Mts. Lakes]. MSc. Thesis, Komenského univerzita v Bratislave, Bratislava, 50 pp.
Poláková L. & Štefková E. 2006. Rozsievky sedimentov vybraných tatranských plies [Diatoms of the sediments of selected Tatra Mts. Lakes], p. 63. In: Sacherová V. (ed.), Sborník příspěvků 14. konference České Limnologické Společnosti a Slovenskej Limnologickej Spoločnosti, 26–30 June 2006, Nečtiny, 166 pp. ISBN: 80-239-7257-X
Potůčková A. 2014. Rekonstrukce paleo-environmentálních poměrů zaniklého jezera Šúr v pozdním glaciálu a holocénu pomocí analýzy makrozbytků [Reconstruction of environmental changes of the paleo-lake Šúr during the Late Glacial and Holocene using macrofossil analysis]. MSc. Thesis, Karlova univerzita v Prahe, Praha, 87 pp. https://is.cuni.cz/webapps/zzp/detail/130857/
Rybníčková E. & Rybníček K. 2006. Pollen and macroscopic analyses of sediments from two lakes in the High Tatra mountains, Slovakia. Veg. Hist. Archaeobot. **15:** 345–356. DOI: 10.1007/s00334-006-0050-1
Sacherová V., Kršková R., Stuchlík E., Hořická Z., Hudec I. & Fott J. 2006. Long-term change of the littoral Cladocera in the Tatra Mountain lakes through a major acidification event. Biologia **61 (Suppl 18):** S109–S119. DOI: 10.2478/s11756-006-0124-7
Stasiak J. 1984. Wiek i ewolucja Szczyrbskiego jeziora [The age and evolution of lake Štrbské pleso]. Prace i Studia Geograficzne **5:** 71–80.
Stuchlík E., Appleby P., Bitušík P., Curtis C., Fott J., Kopáček J. Pražáková M., Rose N., Strunecký O. & Wright R.F. 2001. Reconstruction of long-term changes in lake water chemistry, zooplankton and benthos of a small, acidified high-mountain lake: magic modelling and palaeolimnological analysis. Water Air Soil Pollut.: Focus **2 (2):** 127–138. DOI: 10.1023/A:1020198424308
Svitok M. Kubovčík V. Appleby P. G. Kopáček, J. & Bitušík, P. 2012. Fauna pakomárov horského jazera: kombinácia paleo- a neolimnologického prístupu pri hodnotení zotavovania z acidifikácie [Chironomids of a mountain lake: combination of paleo- and neolimnological approach to assess the recovery from acidification], p. 157. In: Čiamporová-Zaťovičová Z. (ed.), Zborník príspevkov z XVI. konferencie ČLS a SLS, 25–29 June 2012, Jasná, 235 pp. ISBN: 978-80-971056-0-0
Šporka F., Štefková E., Bitušík P., Thomson A.R., Augusti-Panareda A., Appleby P.G., Grytnes J.A. Kamenik C., Krno I., Lami A., Rose N. & Shilland N.E. 2002. The paleolimnological analysis of sediments from high mountain lake Nižné Terianske pleso in the High Tatras (Slovakia). J. Paleolimnol. **28:** 95–109. DOI: 10.1023/A:1020376003123.
Štefková E. 2001. Rozsievky Nižného Terianskeho plesa a Starolesnianskeho plesa vo Vysokých Tatrách [Diatoms of lakes Terianske pleso and Starolesnianske pleso, High Tatra Mts]. PhD Thesis, Komenského univerzita v Bratislave, Bratislava, 117 pp.
Štefková E. 2003. Rozsievky vybraných jazier Vysokých Tatier [Diatoms of selected lakes of the High Tatra Mts]. Acta Fac. Ecol. Zvolen **10:** 77–79.
Štefková E. 2009. Porovnanie spoločenstiev rozsievok tatranských plies v období pred industrializáciou a v súčasnosti [Comparison of diatom communities of the Tatra Mts. lakes in the pre-industrialisation period and nowadays], pp. 259–262. In: Kröpfelová L. & Šulcová J. (eds), Sborník příspěvků 15. konference České limnologické společnosti a Slovenskej limnologickej spoločnosti, Třeboň, 22–26 June 2009, Třeboň, 305 pp. ISBN: 978-80-254-4698-0
Štefková E. & Šporka F. 2001. Long-term ecological research of high mountain lakes in the High Tatras (Slovakia). Ekológia **20 (Suppl. 2):** 101–106.
Wacnik A. 1995. The vegetational history of local flora and evidences of human activities recorded in the pollen diagram from side Regetovka, NE Slovakia. Acta Palaeobot. **35:** 253–274.

Received April 5, 2017
Accepted October 11, 2017