DE GRUYTER

Biologia **72**/8: 965—969, 2017
Section Zoology
DOI: 10.1515/biolog-2017-0102
Short Communication

Relict chironomid communities surviving in the coldest High Tatra Mountain lakes confirmed by a palaeolimnological survey

Peter Bitušík[1], Daniela Dobríková[1], Radovan Pipík[2] & Ladislav Hamerlík[1,3]

[1]*Department of Biology and Ecology, Faculty of Natural Sciences, Matej Bel University, Tajovského 40, SK-97401 Banská Bystrica, Slovakia; e-mail: peter.bitusik@umb.sk*
[2]*Earth Science Institute, Slovak Academy of Sciences, Ďumbierska 1, SK-97401 Banská Bystrica, Slovakia*
[3]*Institute of Geological Sciences, Polish Academy of Sciences, Twarda 51/55, 00-818 Warsaw, Poland*

Abstract: The climatically most extreme lakes in the High Tatra Mountains are populated with species-poor chironomid communities dominated by *Micropsectra radialis* and *Pseudodiamesa nivosa*. Based on paleolimnological studies from other parts of Europe this community had been hypothesized to be a relict of the Late Glacial period, however, this assumption has not been proved in the Tatras. A paleolimnological survey of a subalpine Tatra lake demonstrated that this community was indeed occupying lakes located even in relatively low altitudes as long as they were glacially influenced, i.e., until the early Holocene. Due to the restricted distribution and specific ecological requirements of the species creating this relict community, it is extremely prone to extinction.

Key words: glaciation; glacial relicts; mountain glaciers; mountain lakes; Chironomidae; Late-Glacial; Slovakia

Introduction

Relict species as remnants of old times or fascinating 'living fossils' have always attracted the attention of scientists and naturalists (Grandcolas et al. 2014). The origin and distribution of modern-day relicts can often be related to the past environmental changes. Climatic oscillations in the Quaternary forced organisms to shift geographical distribution as they spread to more favourable conditions (Hewitt 1999). Many temperate species that are widespread today existed as small relict populations just a few thousand years ago, and, on the other hand, many cold-adapted species formerly widely distributed, survive now in restricted areas in high mountain ranges (e.g., Schmitt 2007). Despite the differences in detailed distributional types, the last mentioned species show recently disjunct distribution patterns in European mountain systems and, in some case, in the Arctic (Schmitt 2009). The term "geographic relicts" is used for such descendants of once widespread populations (Lomolino et al. 2006). These species are reduced to few populations restricted to small number of locations, e.g., isolated mountain peaks, valleys or lakes. Consequently, relict species are considered as threatened or endangered what makes them especially important for nature conservation.

Similar to other European mountain ranges, numerous relict and endemic taxa are known in the Carpathians. In terms of occurrence of these species, perhaps the most important part of the Western Carpathians is its highest part, the Tatra Mountains (Kadlečík 2014; Kliment et al. 2016).

Extensive limnological survey of the Tatra Mts revealed a chironomid community dominated by *Micropsectra radialis* (Goetghebuer, 1939) and *Pseudodiamesa nivosa* (Goetghebuer, 1928) characteristic of the lakes situated in the alpine zone above 2000 m a.s.l. (Bitušík et al. 2006). This community has been hypothesized to be a relict of the Late-Glacial period. However, this assumption was based on ecological requirements and recent and past distribution of both dominant species (e.g., Hoffmann 1988; Larocque et al. 2001; Nyman & Korhola 2005; Boggero et al. 2006; Lods-Crozet et al. 2012; Luoto et al. 2013, 2014), and have never been proved.

Using a paleolimnological reconstruction of a subalpine Tatra lake, our goal was to prove that a community dominated by *M. radialis* and *P. nivosa* populated the Tatra lakes when glaciers were present in their catchments and that this community disappeared with the retreat of the glacier from the valleys.

Methods

Study site
Lake Popradské pleso (49°09′13″ N, 20°04′47″ E) is situated in the Mengusovská dolina valley, High Tatra Mts, at 1494 m a.s.l. The lake has a maximum and average depth of 17 m and 7 m, respectively; the lake surface reaches 6.8 ha (Gregor & Pacl 2005). Popradské pleso is an ideal site for deglaciation studies, since due to its relatively low altitude

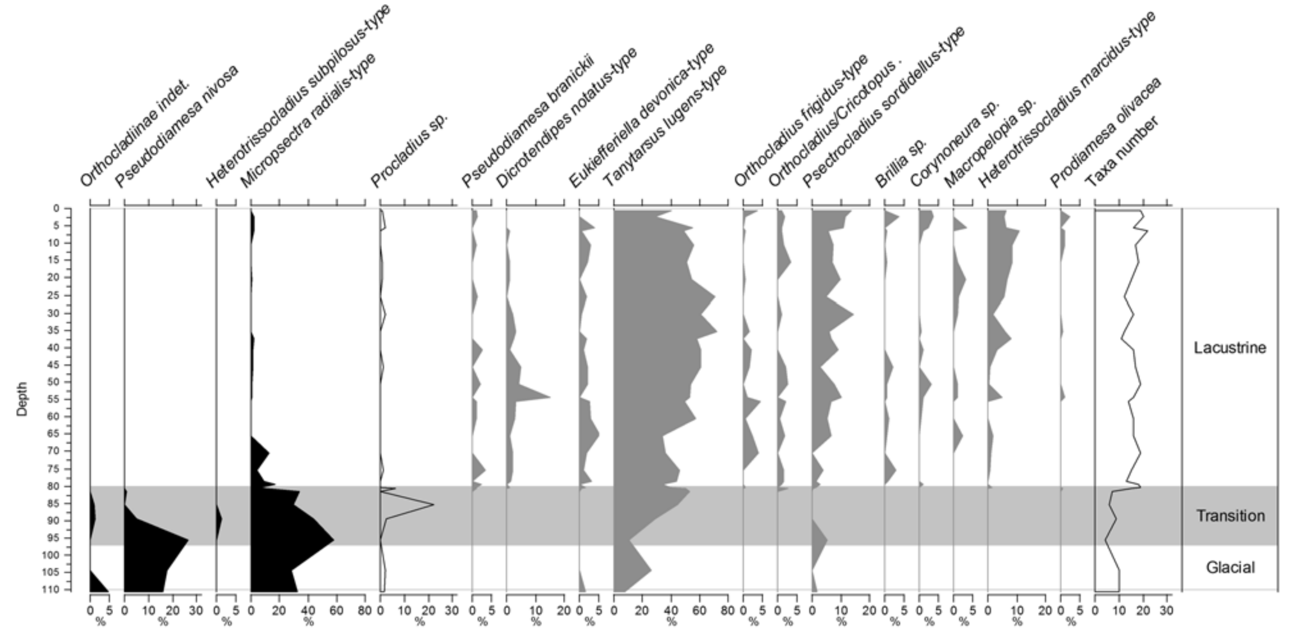

Fig. 1. Stratigraphic changes of the chironomid community (% abundance) of the lake Popradské pleso over the last more than 8000 years. Taxa are ordered according to their weighed average scores and only taxa characteristic for the different zones are shown. Black colour refers to taxa characteristic for the glacially influenced period of the lake; grey colour show taxa typical for the period after the glacial retreat; transparent chart stands for the taxon that reached highest proportion in the transition layer. Only the uppermost 110 cm of the total 340 cm long sediment sequence is shown.

it belongs to the oldest glacial lakes in the Tatra Mts. The lake is dimictic, it has an inflow and an outflow and harbours a natural population of brown trout (*Salmo trutta* L., 1758). Most of the lake's catchment area is located in the alpine zone and consists mainly of bedrock, debris and alpine meadows; only ∼ 14% of the catchment is covered by forest. For the comprehensive description of the study lake see Hamerlík et al. (2016) and references therein.

Field and laboratory works

The bottom of Popradské pleso was surveyed using a sub-bottom profiler SB-216S to find the maximum deposit thickness for drilling. Subsequently, two long, overlapping cores with a total length of 340 cm of sedimentary record were taken from a sampling platform using a UWITEC Niederreiter 60 type hydraulic corer in May 2013. Both sediment cores were transferred to laboratory and sectioned in 1 cm sequences. For detailed description of the coring and the *a priori* sediment survey see Pipík et al. (submitted). Even though the total length of the sediment core is 340 cm, in the present study we focused only on the uppermost 110 cm of it, representing the transition from glaciated to non-glacial system. The sediment sequence from 110 to 340 cm is glacially laminated and is currently being processed.

The age-depth model was calculated based on ^{14}C ages of plant macrofossils (conifer needles and twig) found within the uppermost 79 cm of the sediment core. Due to high liquefaction of the organic deposits, approximately one meter of the uppermost sediment was missing from the core, thus it was impossible to develop a chronology for sediments above the uppermost dated level. According to the dating, the transition from the glacially influenced system (varved sediments) to lacustrine system (gyttja sediments) took place about 8787.5 ± 192.5 cal BP.

Sediment samples for chironomid analysis were processed using a standard technique sensu Walker & Paterson (1985). A minimum of 50 chironomid head capsules per sample were hand-picked under a binocular microscope (40× magnification) and permanently mounted in Berlese medium. Taxonomic identification was performed using a compound microscope with reference to Brooks et al. (2007) and Andersen et al. (2013).

C2 software version 1.7.7 (Juggins 2007) was used for visualising stratigraphic changes of the relative abundance (%) of chironomids in the first 110 cm of the sediment core. Taxa were sorted by their weighted average of their sample number. This method allows ordering the species/taxa in terms of their occurrence in the core, which provide a useful starting point for their order in a stratigraphic diagram.

Results

From sedimentological point of view the sediment core consists of three main lithologically different zones reflecting altered environmental conditions of the lake. The laminated bottom sediment (from 340 to 97 cm) refers to the Early Holocene under a strong glacial influence. The uppermost (80–0 cm) dark brown homogenous gyttja zone represents Mid-Holocene lake deposits after the disappearance of the glacier from the valley. The light greyish-brownish plastic slightly stratified silt layer between these zones (97–80 cm) indicates a transition between the two main zones.

The chironomid composition corresponds well with the lithological changes in the sediment (Fig. 1). While low taxonomic richness was characteristic for the glacially influenced zone (10 taxa on average), richness suddenly increased at the end of the transition zone by almost twofold and remained high in the gyttja layer (16 taxa on average, 22 max). The glacially influenced and non-glacial (gyttja) zones differed considerably also in community structure. *Pseudodiamesa nivosa* and *Micropsectra radialis*-type highly dominated

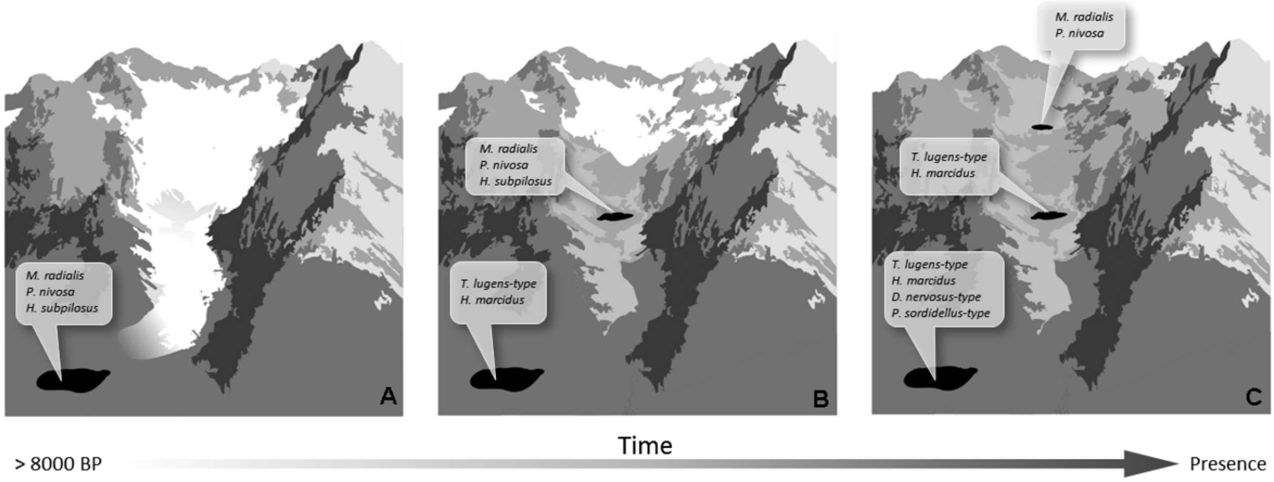

Fig. 2. A schematic representation of the possible changes in chironomid communities in the High Tatra lakes during and after the last glaciation. Species that were typical for the lowermost lakes for the time when the valleys were glaciated (A) has gradually moved upwards when the glacial retreated leaving new lakes behind (B) or went extinct (*H. subpilosus*). Nowadays, glacial relicts *M. radialis* and *P. nivosa* are only surviving in the coldest uppermost lakes, while new species invade to the Tatra lakes from lower areas (C). Glacier is symbolized with white colour, lakes are marked with black.

(~ 30% and ~ 17%, respectively) the glacially influenced layers with *P. nivosa* only being present in this part of the sediment. In the transition zone the relative abundance of *M. radialis*-type rapidly diminished and even though it was occasionally recorded in the younger sequences, its proportion remained very low (~ 2%). *Heterotrissocladius subpilosus* type was only recorded in the transition zone. The relative abundance of *Procladius* sp. peaks in the transition zone (< 22%), but above and below it was only found in small amounts (< 2%). Taxa characteristic for the recent community of the lake, such as *Tanytarsus* sp., *Tanytarsus lugens* type, *Macropelopia* sp., *Dicrotendipes nervosus* type, *Psectrocladius sordidellus* type and *Heterotrissocladius marcidus* (Walker, 1856) became common in the gyttja zone. *Pseudodiamesa nivosa* was replaced by *P. branickii* (Nowicki, 1873).

Discussion

Even though *M. radialis* and *P. nivosa* recently occur together in several High Tatra lakes (Bitušík et al. 2006), remarkably, the almost exact qualitative and quantitative composition of the subfossil community found in the glacially influenced zone was so far recorded only in two of them. Detailed studies of the recent and subfossil larval material from Ľadové pleso lake (Tátosová & Stuchlík 2006; Kubovčík & Bitušík 2006) revealed a species poor chironomid community with the dominance of *M. radialis*, whereas larvae of *P. nivosa* were common but less abundant; other species were represented only sparsely. Similar taxonomic composition was found in Vyšné Wahlenbergovo pleso lake, however, with higher proportion of *H. marcidus* (Hamerlík & Bitušík 2009) that became an important faunal component since the 1930s (Bitušík et al. 2009).

Even though both *M. radialis* and *P. nivosa* have been recorded in many European countries (15 and 20, respectively; Sæther & Spies 2013), their strictly cold-stenothermic and polyoxybiontic feature resulted in strongly disjunct distribution patterns, since they are bind to extremely cold water bodies in high altitudes and latitudes (Rossaro 1991; Heiri et al. 2011; Eggermont & Heiri 2012).

There are slight differences in habitat preferences of *M. radialis* and *P. nivosa*. While *M. radialis* is a typical inhabitant of alpine lakes in the European mountain systems (e.g., Giłka 2011), *P. nivosa* is adapted to harsher physical environments, including freezing and drying in alpine ponds and lakes; it can even colonize cold habitats of the periglacial zones at lower altitudes (see Ilyashuk et al. 2010, citation therein). Hofmann (1971) demonstrated that *M. radialis,* like other cold-adapted chironomids, occupied littoral of lakes created by the last glaciation. Later, during the warmer Atlantic climate it either disappeared from shallow lakes or migrated from the littoral into the profundal. Current distribution of *M. radialis* in the Tatra lakes coincides with this scheme very well. It only occurs in lakes with extremely cold thermal regimes, usually situated at high elevation; at the same time it is absent in relatively warmer subalpine lakes with the exception of some deep lakes with a cold and well-oxygenated hypolimnetic zone (Bitušík et al. 2006). *P. nivosa* seems to be more widely distributed along the altitudinal and temperature gradients of the Tatra Mts and it dwells a wide range of water bodies from small alpine ponds (Hamerlík et al. 2017) to deep lakes (Bitušík et al. 2006).

It has already been shown that climatic amelioration, i.e., increased air and in turn water temperatures, can significantly change the structure of chironomid communities (see Walker 2001 and references therein). This was probably the case of the unexpected increase of *H. marcidus* in the sediment sequence of Vyšné Wahlenbergovo pleso since the 1930s (Bitušík et al. 2009) that was most likely connected to the warmer climate following the end of the Little Ice Age (Kłapyta et al. 2016). Nowadays we are witnessing a gradual upslope movement of species typical for lower altitudes. Since 2000 and/or 2004 some species previously only recorded in warmer sub-alpine lakes, such as *Macropelopia* cf. *nebulosa* (Meigen, 1804), *Zavrelimyia* sp., *Corynoneura scutellata* group, *Psectrocladius* (*P.*) *limbatellus*/*sordidellus* group and *Paratanytarsus austriacus* Kieffer, 1924 have started to appear more or less regularly in some alpine lakes (unpublished data). Their up-slope dispersal to the lakes at higher altitude is most likely connected with the climatic warming observed in the Tatra Mts over the last two decades when the annual mean temperature increased by 1.1 °C (Svitok, unpubl. data). Again, the upward movement of thermally plastic taxa is in a good accordance with the community development recorded in the sediment sequence of Popradské pleso after the retreat of the glacier (Fig. 2). In this section of the core, the above mentioned taxa become common at the expense of the relict taxa that became less important or disappeared (Fig. 1). With further warming in the Tatra Mts, this can potentially happen to the relict community dominated by *M. radialis* and *P. nivosa* in the close future. Because they are surviving together only in few isolated lakes, their restricted distribution and specific ecological requirements make them as a relict community extremely prone to extinction.

Our findings underline the importance of paleolimnological survey in mountainous areas and show that palaeolimnological data can indeed indicate present and future scenarios of possible biological changes in the mountain environment caused by climatic warming.

Acknowledgements

We are grateful to Jan Bitusik for designing and drawing Figure 2. This work was co-supported by projects VEGA 1/0664/15, APVV-15-0292, Grant Agency of the Czech Republic P504-17-15229S and ITMS 26210120024.

References

Andersen T., Cranston P.S. & Epler J.H. (eds). 2013. Chironomidae of the Holarctic Region – Keys and diagnoses – Larvae. Series: Insect Systematics and Evolution Supplements 66, 573 pp. ISBN-13: 9789163746680

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

Bitušík P., Svitok M., Kološta P. & Hubková M. 2006. Classification of the Tatra Mountains lakes (Slovakia) using chironomids (Diptera, Chironomidae). Biologia **61 (Suppl. 18):** S191–S202. DOI: 10.2478/s11756-006-0131-8

Boggero A., Füreder L., Lencioni V., Simcic T., Thaler B., Ferrarese U., Lotter A.F. & Ettinger R. 2006. Littoral chironomid communities of Alpine lakes in relation to environmental factors. Hydrobiologia **562:** 145–165. DOI: 10.1007/s10750-005-1809-6

Brooks S.J., Langdon P.G. & Heiri O. 2007. The Identification and Use of Palaearctic Chironomidae Larvae in Palaeoecology. Technical guide No. 10, Quaternary Research Association, London, 276 pp. ISBN: 0907780717, 9780907780717

Eggermont H. & Heiri O. 2012. The chironomid-temperature relationship: expression in nature and palaeoenvironmental implications. Biol. Rev. **87 (2):** 430–456. DOI: 10.1111/j.1469-185X.2011.00206.x

Giłka W. 2011. Analiza różnorodności faunistycznej ochotkowatych z plemienia Tanytarsini w Europie (Diptera: Chironomidae) [Analysis of faunistic diversity in chironomids of the tribe Tanytarsini in Europe (Diptera: Chironomidae)]. Dipteron, Bulletin of the Dipterological Section of the Polish Entomological Society **27:** 11–31.

Grandcolas P., Nattier R. & Trewick S. 2014. Relict species: a relict concept? Trends Ecol. Evol. **29 (12):** 655–663. DOI: 10.1016/j.tree.2014.10.002

Gregor V. & Pacl J. 2005. Hydrológia tatranských jazier [Hydrology of the Tatra Mountain lakes]. Acta Hydrologica Slovaca **6 (1):** 161–187.

Hamerlík L. & Bitušík P. 2009. The distribution of littoral chironomids along an altitudinal gradient in High Tatra Mountain lakes: Could they be used as indicators of climate change? Ann. Limnol. – Int. J. Lim. **45:** 145–156. DOI: 10.1051/limn/2009021

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

Hamerlík L., Svitok M., Novikmec M., Veselská, M. & Bitušík P. 2017. Weak altitudinal pattern of overall chironomid richness is a result of contrasting trends of subfamilies in high-altitude ponds. Hydrobiologia **793 (1):** 67–81. DOI: 10.1007/s10750-016-2992-3

Heiri O., Brooks S.J., Birks H.J.B. & Lotter A.F. 2011. A 274-lake calibration data-set and inference model for chironomid-based summer air temperature reconstruction in Europe. Quatern. Sci. Rev. **30 (23-24):** 3445–3456. DOI: 10.1016/j.quascirev.2011.09.006

Hewitt G.M. 1999. Post-glacial re-colonization of European biota. Biol. J. Linn. Soc. **68 (1-2):** 87–112. DOI: 10.1111/j.1095-8312.1999.tb01160.x

Hofmann W. 1971. Die postglaziale Entwicklung der Chironomiden- und *Chaoborus*- Fauna (Dipt.) des Schöhsees. Arch. Hydrobiol., Suppl. **40 (1/2):** 1–74.

Hofmann W. 1988. The significance of chironomid analysis (Insecta: Diptera) for paleolimnological research. Palaeogeogr. Palaeoclimat. Palaeoecol. **62 (1-4):** 501–509. DOI: 10.1016/0031-0182(88)90070-3

Ilyashuk B.P., Ilyashuk E.A., Makarchenko E.A. & Heiri O. 2010. Midges of the genus Pseudodiamesa Goetghebuer (Diptera, Chironomidae): current knowledge and palaeoecological perspective. J. Paleolimnol. **44 (2):** 667–676. DOI: 10.1007/s10933-010-9446-0

Juggins S. 2007. C2: Software for Ecological and Palaeoecological Data Analysis and Visualisation (User Guide Version 1.7.7). Newcastle upon Tyne: Newcastle University, 77. https://www.staff.ncl.ac.uk/stephen.juggins/software/C2Home.htm (accessed 01.02.2017)

Kadlečík J. 2014. Carpathian Red List of Forest Habitats and Species, Carpathian List of Invasive Alien Species (draft). The State Nature Conservancy of Slovak Republic. Banská Bystrica, 234 pp. ISBN: 978-80-89310-81-4

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

Kliment J., Turis P. & Janišová M. 2016. Taxa of vascular plants endemic to the Carpathian Mts. Preslia **88 (1):** 19–76.

Kubovčík V. & Bitušík P. 2006. Subfossil chironomids (Diptera, Chironomidae) in three Tatra Mountain lakes (Slovakia) on an acidification gradient. Biologia **61 (Suppl. 18):** S215–S222. DOI: 10.2478/s11756-006-0133-6

Larocque I., Hall R.I. & Grahn E. 2001. Chironomids as indicators of climate change: a 100-lake training set from a subarctic region of northern Sweden (Lapland). J. Paleolimnol. **26 (3):** 307−322. DOI: 10.1023/A:1017524101783

Lods-Crozet B., Oertli B. & Robinson C.T. 2012. Long-term Patterns of Chironomid Assemblages in a High Elevation Stream/Lake Network (Switzerland). Implications to Global Change. Fauna Norv. **31:** 71–85. DOI: 10.5324/fn.v31i0.1361

Lomolino M.V., Riddle B.R. & Brown J.H. 2006. Biogeography. 3rd edn Sinauer Associates. Sunderland, MA, 845 pp. ISBN: 0–87893–062–0

Luoto T.P., Kaukolehto M. & Nevalainen L. 2014. The relationship between water and air temperature in chironomid-based paleoclimate reconstructions: Records from boreal and subarctic Finland. The Holocene **24 (11):** 1584–1590. DOI: 10.1177/0959683614544056

Luoto T.P., Salonen V.-P., Larocque-Tobler I., Pienitz R., Hausmann S., Guyard H. & St-Onge G. 2013. Pro- and postglacial invertebrate communities of Pingualuit Crater Lake, Nunavik (Canada), and their paleoenvironmental implications. Freshwater Sci. **32 (3):** 951–963. DOI: 10.1899/12-178.1

Nyman M.T. & Korhola A. 2005. Chironomid-based classification of lakes in western Finnish Lapland. Boreal Env. Res. **10 (4):** 239–254.

Rossaro B. 1991. Chironomids and water temperature. Aquatic Insects **13 (2):** 87–98. DOI: 10.1080/01650429109361428

Sæther O.A. & Spies M. 2013. Fauna Europaea: Chironomidae. In: Beuk P., Pape T. & de Jong Y.S.D.M. (eds), Fauna Europaea: Diptera, Nematocera. Fauna Europaea version 2.6, http//www. faunaeur.org

Schmitt T. 2007. Molecular biogeography of Europe: pleistocene cycles and postglacial trends. Front. Zool. **4:** 11. DOI: 10.1186/1742-9994-4-11

Schmitt T. 2009. Biogeographical and evolutionary importance of the European high mountain systems. Front. Zool. **6:** 9. DOI: 10.1186/1742-9994-6-9

Tátosová J. & Stuchlík E. 2006. Seasonal dynamics of chironomids in the profundal zone of a mountain lake (Ľadové pleso, the Tatra Mountains, Slovakia). Biologia **61 (Suppl. 18): S**203–S212. DOI: 10.2478/s11756-006-0132-7

Walker I.R. 2001. Midges: Chironomidae and related Diptera, pp. 43–66. DOI: 10.1007/0-306-47671-1_3. In: Smol J.P., Birks H.J.B. & Last W.M. (eds), Tracking Environmental Change Using Lake Sediments, Vol. 4, Zoological Indicators, Series Title: Developments in Paleoenvironmental Research, Kluwer Academic publishers, Dordrecht, The Netherlands, 218 pp. ISBN: 978-90-481-6034-1

Walker I.R. & Paterson C.G. 1985. Efficient separation of subfossil Chironomidae from lake sediments. Hydrobiologia **122 (2):** 189–192. DOI: 10.1007/BF00032107

Received March 30, 2017
Accepted May 16, 2017