Boreas 2020 vol.49 N3, pages 544-561

The Late Pleistocene–Early Holocene palaeoenvironmental evolution in the SE Baltic region: a new approach based on chironomid, geochemical and isotopic data from Kamyshovoye Lake, Russia

Druzhinina O., Kublitskiy Y., Stančikaitė M., Nazarova L., Syrykh L., Gedminienė L., Uogintas D., Skipityte R., Arslanov K., Vaikutienė G., Kulkova M., Subetto D.
Kazan Federal University, 420008, Kremlevskaya 18, Kazan, Russia

Abstract

© 2020 Collegium Boreas. Published by John Wiley & Sons Ltd The Kamyshovoye Lake sedimentary record in the southeastern Baltic Sea region was studied to reconstruct climatic fluctuations and the abiotic responses to them during the Lateglacial and Early Holocene. New results from chironomid, isotopic, palaeomagnetic and geochemical data analyses were correlated with earlier evidence of lithological and palynological changes in the Kamyshovoye Lake record. The section of the record that was studied covered the interval between 15 200 and 6500 cal. a BP. Palaeoclimatic reconstructions showed that during the Younger Dryas there was a two-step decrease in the mean July temperature. The temperature dropped by 3 °C in the period from˜12 650 to 12 300 cal. a BP, and then it dropped by another 0.5 °C to a minimum of 11.5 °C at 11 900 cal. a BP. During the Younger Dryas–Holocene transition, a temperature increase of 3 °C can be seen over a period of several centuries, inferred from the chironomid data. Further, the temperature curve showed that significant fluctuations continued until ˜9500 cal. a BP. During the coolings, the average July temperature dropped to values that were typical for the Younger Dryas, while values characteristic for the Allerød were only reached at around 9700 cal. a BP. After 9500 cal. a BP, a more stable, gradual increase in temperature was recorded. The short-term Early Holocene climatic oscillations are clearly traced in the Kamyshovoye sequence, although the responses of the natural components are sometimes asynchronous. In the case of the Kamyshovoye study, the geochemical data seem to be a sensitive indicator of the climatic and environmental changes despite the absence of an evident response to the Holocene onset at˜11 700 cal. a BP. Considerable changes in the geochemical pattern are recorded later, at˜11 500 cal. a BP, coinciding with noticeable changes in the development of vegetation. The results obtained in this study contribute to a deeper understanding of how global climatic trends are manifested on a local scale.

http://dx.doi.org/10.1111/bor.12438

References

[1] Ammann, B., von Grafenstein, U. & van Raden, U. J. 2013a: Biotic responses to rapid warming about 14,685 yr BP: introduction to a case study at Gerzensee (Switzerland). Palaeogeography, Palaeoclimatology, Palaeoecology 391, 3–12.

[2] Ammann, B., van Leeuwen, J. F. N., van der Knaap, W. O., Lischke, H., Heiri, O. & Tinner, W. 2013b: Vegetation responses to rapid warming and to minor climatic fluctuations during the Late-Glacial Interstadial (GI-1) at Gerzensee (Switzerland). Palaeogeography, Palaeoclimatology, Palaeoecology 391, 40–59.

[3] Apolinarska, K., Woszczyk, M. & Obremska, M. 2012: Late Weichselian and Holocene palaeoenvironmental changes in northern Poland based on the Lake Skrzynka record. Boreas 41, 292–307.

[4] Arslanov, Kh., Druzhinina, O., Savelieva, L., Subetto, D., Skhodnov, I., Dolukhanov, P., Kuzmin, G., Chernov, S., Maksimov, F. & Kovalenkov, S. 2011: Geochronology of vegetation stages of south-east Baltic coast (Kaliningrad region) during the Middle and Late Holocene. Geochronometria 38, 172–181.

[5] Bartlein, P. J., Harrison, S. P., Brewer, S., Connor, S., Davis, B. A. S., Gajewski, K., Guiot, J., Harrison-Prentice, T. I., Henderson, A., Peyron, O., Prentice, I. C., Scholze, M., Seppä, H., Shuman, B., Sugita, S., Thompson, R. S., Viau, A. E., Williams, J. & Wu, H. 2011: Pollen based continental climate reconstructions at 6 and 21 ka: a global synthesis. Climate Dynamics 37, 755–802.

[6] Bennett, K. D. 1996: Determination of the number of zones in a biostratigraphical sequence. New Phytologist 132, 155–170.

[7] Birks, H. J. B. 1995: Quantitative palaeoenvironmental reconstructions. In Maddy, D. & Brew, J. S. (eds.): Statistical Modelling of Quaternary Science Data, 161–254. Quaternary Research Association, Cambridge.

[8] Birks, H. J. B. 1998: Numerical tools in palaeolimnology – progress, potentialities, and problems. Journal of Paleolimnology 20, 307–332.

[9] Birks, H. J. B. & Gordon, A. D. 1985: The analysis of pollen stratigraphical data: zonation. In Birks, H. J. B. & Gordon, A. D. (eds.): Numerical Methods in Quaternary Pollen Analysis, 47–90. Academic Press, London.

[10] Birks, H. J. B., Line, J. M., Juggins, S., Stevenson, A. C. & ter Braak, C. J. F. 1990: Diatoms and pH reconstruction. Philosophical Transactions of the Royal Society of London, Series B 327, 263–278.

[11] Björck, S., Muscheler, R., Kromer, B., Andresen, C. S., Heinemeier, J., Johnsen, S. J., Conley, D., Koc, N., Spurk, M. & Veski, S. 2001: High-resolution analyses of an early Holocene climate event: may imply decreased solar forcing as an important climate trigger. Geology 29, 1107–1110.

[12] Björck, S., Rundgren, M., Ingólfsson, Ó. & Funder, S. 1997: The Preboreal Oscillation around the Nordic Seas: terrestrial and lacustrine responses. Journal of Quaternary Science 12, 455–465.

[13] Bohncke, S. & Hoek, W. 2007: Multiple oscillations during the Preboreal as recorded in a calcareous gyttja, Kingbeekdal, The Netherlands. Quaternary Science Reviews 26, 1965–1974.

[14] Borzenkova, I. I., Zorita, E., Borisova, O. K., Kalnina, L., Kisieliene, D., Koff, T., Kuznetsov, D., Lemdahl, G., Sapelko, T., Stancikaite, M. & Subetto, D. 2015: Second Assessment of Climate Change for the Baltic Sea Basin. 501 pp. Springer Verlag, Heidelberg.

[15] Brauer, A., Haug, G. H., Dulski, P., Sigman, D. M. & Negendank, J. F. W. 2008: An abrupt wind shift in western Europe at the onset of the Younger Dryas cold period. Nature Geoscience 1, 520–523.

[16] Bronk Ramsey, C. & Lee, S. 2013: Recent and planned developments of the program OxCal. Radiocarbon 55, 720–730.

[17] Brooks, S. J. & Birks, H. J. B. 2001: Chironomid inferred air temperature from late glacial and Holocene sites in north-west Europe: progress and problems. Quaternary Science Reviews 20, 1723–1741.

[18] Brooks, S. J., Langdon, P. G. & Heiri, O. 2007: The Identification and Use of Palaearctic Chironomidae Larvae in Palaeoecology. QRA Technical Guide 10, 276 pp. Quaternary Research Association, London.

[19] Broström, A., Nielsen, A. B., Gaillard, M.-J., Hjelle, K., Mazier, F., Binney, H., Biuitiug, J., Fyfe, R., Meltsov, V., Poska, A., Rasanen, S., Soepboer, W., von Stedingk, H. & Sugita, S. 2008: Pollen productivity estimates of key European plant taxa for quantitative reconstruction of past vegetation: a review. Vegetation History and Archaeobotany 17, 461–478.

[20] Czernik, J. 2009: Radiocarbon dating of late-glacial bottom sediments of Lakes Gościąż and Miłkowskie by the accelerator mass spectrometry. Acta Palaeobotanica 49, 337–352.

[21] De Klerk, P., Couwenberg, J. & Joosten, H. 2007: Shortlived vegetational and environmental change during the Preboreal in the Biebrza Upper Basin (NE Poland). Quaternary Science Reviews 26, 1975–1988.

[22] Druzhinina, O., Subetto, D., Stančikait≐, M., Vaikutien≐, G., Kublitsky, J. & Arslanov, K. 2015: Sediment record from the Kamyshovoye Lake: history of vegetation during late Pleistocene and early Holocene (Kaliningrad District, Russia). Baltica 28, 121–134.

[23] Dzieduszyńska, D., Kittel, P., Petera-Zganiacz, J., Brooks, S., Korzeń, K., Krapiec, M., Pawłowski, D., Płaza, D., Płóciennik, M., Stachowicz-Rybka, R. & Twardy, J. 2014: Environmental influence on forest development and decline in the Warta River valley (Central Poland) during the Late Weichselian. Quaternary International 324, 99–114.

[24] Gaidamavičius, A., Stančikait≐, M., Kisielien≐, D., Mažeika, J. & Gryguc, G. 2011: Post-glacial vegetation and environment of the Labanoras region, East Lithuania: implications for regional history. Geological Quarterly 55, 269–284.

[25] Gałka, M. & Sznel, M. 2013: Late Glacial and Early Holocene development of lakes in northeastern Poland in view of plant macrofossil analyses. Quaternary International 292, 124–135.

[26] Gałka, M., Tobolski, K. & Bubak, I. 2015: Late Glacial and Early Holocene lake level fluctuations in NE Poland tracked by macro-fossil, pollen and diatom records. Quaternary International 388, 23–38.

[27] Gałka, M., Tobolski, K., Zawisza, E. & Goslar, T. 2014: Postglacial history of vegetation, human activity and lake-level changes at Jezioro Linówek in northeast Poland, based on multi-proxy data. Vegetation History and Archaeobotany 23, 123–152.

[28] Guobyt≐, R. & Satkūnas, J. 2011: Pleistocene glaciations in Lithuania. In Ehlers, J., Gibbard, P. L. & Hughes, P. D. (eds.): Quaternary Glaciations Extent and Chronology – A Closer Look, 231–246. Elsevier, Amsterdam.

[29] Heikkilä, M. & Seppä, H. 2010: Holocene climate dynamics in Latvia, eastern Baltic region: a pollen-based summer temperature reconstruction and regional comparison. Boreas 39, 705–719.

[30] Heiri, O., Brooks, S. J., Renssen, H., Bedford, A., Hazekamp, M., Ilyashuk, B., Jeffers, E. S., Lang, B., Kirilova, E., Kuiper, S., Millet, L., Samartin, S., Tóth, M., Verbruggen, F., Watson, J. E., van Asch, N., Lammertsma, E., Amon, L., Birks, H. H., Birks, H. J. B., Mortensen, M. F., Hoek, W. Z., Magyari, E., Sobrino, C. M., Seppä, H., Tinner, W., Tonkov, S., Veski, S. & Lotter, A. F. 2014: Validation of climate model-inferred regional temperature change for late-glacial Europe. Nature Communications 5, 4914, https://doi.org/10.1038/ncomms5914.

[31] Heiri, O., Cremer, H., Engels, S., Hoek, W. Z., Peeters, W. & Lotter, A. F. 2007: Lateglacial summer temperatures in the Northwest European lowlands: a chironomid record from Hijkermeer, the Netherlands. Quaternary Science Reviews 26, 2420–2437.

[32] Hill, M. O. 1973: Diversity and evenness: a unifying notation and its consequences. Ecology 54, 427–432.

[33] Juggins, S. 2007: C2 Version 1.5 User guide. Software for ecological and palaeoecological data analysis and visualisation. Department of Geography, University of Newcastle, Newcastle upon Tyne.

[34] Karpinska-Kołaczek, M., Kołaczek, P. & Stachowicz-Rybka, R. 2014: Pathways of woodland succession under low human impact during the last 13,000 years in northeastern Poland. Quaternary International 328–329, 196–212.

[35] Karpinska-Kołaczek, M., Stachowicz-Rybka, R., Obidowicz, A., Woszczyk, M. & Kołaczek, P. 2016: A lake-bog succession vs. climate changes from 13,300 to 5900 cal. BP in NE Poland in the light of palaeobotanical and geochemical proxies. Review of Palaeobotany and Palynology 233, 199–215.

[36] Kittel, P., Płóciennik, M., Borówka, R. K., Okupny, D., Pawłowski, D., Peyron, O., Stachowicz-Rybka, R., Obremska, M. & Cywa, K. 2016: Early Holocene hydrology and environments of the Ner River (Poland). Quaternary Research 85, 187–203.

[37] Kołaczek, P., Kupryjanowicz, M., Karpinska-Kołaczek, M., Szal, M., Winter, H., Danel, W., Pochocka-Szwarc, K. & Stachowicz-Rybka, R. 2013: The Late Glacial and Holocene development of vegetation in the area of a fossil lake in the Skaliska Basin (NE Poland) inferred from pollen analysis and radiocarbon datings. Acta Palaeobotanica 53, 23–52.

[38] Kołaczek, P., Mirosław-Grabowska, J., Karpinska-Kołaczek, M. & Stachowicz-Rybka, R. 2015: Regional and local changes inferred from lacustrine organic matter deposited between the Late Glacial and mid-Holocene in the Skaliska Basin (north-eastern Poland). Quaternary International 388, 51–63.

[39] Krammer, K. & Lange-Bertalot, H. 1991: Bacillariophyceae. 3. Teil: Centrales, Fragilariaceae, Eunotiaceae. In Ettl, H., Gerloff, J., Heynig, H. & Mollenhauer, D. (eds.): Süsswasserflora von Mitteleuropa, Band 2/3, 576 pp. Gustav Fischer Verlag, Stuttgart.

[40] Kublitsky, Y. 2016: The dynamic of nature condition of SE part of Baltic region during Late Neopleistocene and Holocene. Ph.D. thesis, Saint-Petersburg University, 150 pp (in Russian).

[41] Kublitsky, Y. & Subetto, D. 2020: The reconstruction of the formation of lakes and wetlands and the related sedimentation processes in the Russian segment of the Vištytis Upland. In Fedorov, G., Druzhinin, A., Golubeva, E., Subetto, D. & Palmowski, T. (eds.): Baltic Region, The Region of Cooperation/Springer Proceedings in Earth and Environmental Sciences book series (SPEES), 127–135. Springer, Cham.

[42] Kupryjanowicz, M. 2007: Postglacial development of vegetation in the vicinity of the Wigry Lake. Geochronometria 27, 53–66.

[43] Lang, B., Brooks, S. J., Bedford, A., Jones, R., Birks, H. J. B. & Marshall, J. D. 2010: Regional consistency in Lateglacial chironomid-inferred temperatures from five sites in northwest England. Quaternary Science Reviews 29, 1528–1538.

[44] Lange-Bertalot, H., Hofman, G., Werum, M. & Cantonati, M. 2017: Freshwater Benthic Diatoms of Central Europe: over 800 Common Species Used in Ecological Assessment. 924 pp. English edition with updated taxonomy and added species. Koeltz Botanical Books, Schmitten-Oberreifenberg.

[45] Larocque, I. 2001: How many chironomid head capsules are enough? A statistical approach to determine sample size for palaeoclimatic reconstructions. Palaeogeography, Palaeoclimatology, Palaeoecology 172, 133–142.

[46] Lauterbach, S., Brauer, A., Andersen, N., Danielopol, D. L., Dulski, P., Hüls, M., Milecka, K., Namiotko, T., Plessen, B., von Grafenstein, U. & DECLAKES Participants 2011: Multi-proxy evidence for early to mid-Holocene environmental and climatic changes in northeastern Poland. Boreas 40, 57–72.

[47] Litvin, V. 1999a: In Berenbeim, D. & Litvin, V. (eds.): Kaliningradskaya Oblast: Ocherki prirody, 36–54. Yantarny Skaz, Kaliningrad. (in Russian).

[48] Litvin, V. 1999b: Natural landscapes of the Kaliningrad District. In Berenbeim, D. & Litvin, V. (eds.): Kaliningradskaya Oblast: Prirodnye Resursy, 141–151. Yantarny Skaz, Kaliningrad (in Russian).

[49] Lotter, A. F. & Juggins, S. 1991: POLPROF, TRAN and ZONE: programs for plotting, editing and zoning pollen and diatom data. INQUA Subcommission for the study of the Holocene Working Group on Data-Handling Methods, Newsletter 6, 4–6.

[50] Lowe, J. J., Rasmussen, S., Bjorck, S., Hoek, W. Z., Steffense, J. B., Walker, M. J. C., Yu, Z. C. & the INTIMATE Group 2008: Synchronisation of palaeoenvironmental events in the North Atlantic region during the last termination: a revised protocol recommended by the INTIMATE group. Quaternary Science Reviews 27, 6–17.

[51] Luoto, T., Kotrys, B. & Płóciennik, M. 2019: East European chironomid-based calibration model for past summer temperature reconstructions. Climate Research 77, 63–76.

[52] Martin-Puertas, C., Tjallingii, R., Bloemsma, M. & Brauer, A. 2017: Varved sediment responses to early Holocene climate and environmental changes in Lake Meerfelder Maar (Germany) obtained from multivariate analyses of micro X-ray fluorescence core scanning data. Journal of Quaternary Science 32, 427–436.

[53] Minyuk, P. S., Borkhodoev, V. Y. & Wennrich, V. 2014: Inorganic geochemistry data from Lake El'gygytgyn sediments: marine isotope stages 6–11. Climate of the Past 467–485.

[54] Napreenko-Dorokhova, T. V. 2015: Paleoecological reconstruction of the vegetation cover of the southeastern part of the Baltic region in the Holocene. Ph.D. thesis, Kaliningrad University, 174 pp (in Russian).

[55] Nazarova, L., Herzschuh, U., Wetterich, S., Kumke, T. & Pestjakova, L. 2011: Chironomid-based inference models for estimating mean July air temperature and water depth from lakes in Yakutia, northeastern Russia. Journal of Paleolimnology 45, 57–71.

[56] Nazarova, L., Self, A., Brooks, S. J., van Hardenbroek, M., Herzschuh, U. & Diekmann, B. 2015: Northern Russian chironomid-based modern summer temperature data set and inference models. Global Planetary Change 134, 10–25.

[57] Nazarova, L. B., Self, A. E., Brooks, S. J., Solovieva, N., Syrykh, L. S. & Dauvalter, V. A. 2017: Chironomid fauna of the lakes from the Pechora River Basin (east of European part of Russian Arctic): ecology and reconstruction of recent ecological changes in the region. Contemporary Problems of Ecology 10, 350–362.

[58] Orlenok, V. V., Barinova, G. M., Kucheryavyy, P. P. & Ulyashev, G. L. 2001: Lake Vishtytis; Nature, History, Ecology. 212 pp. Kaliningrad State University Press, Kaliningrad (in Russian).

[59] Peyron, O., Guiot, J., Cheddadi, R., Tarasov, P., Reille, M., de Beaulieu, J. L., Bottema, S. & Andrieu, V. 1998: Climatic reconstruction in Europe for 18,000 yr B.P. from pollen data. Quaternary Research 49, 183–196.

[60] Płóciennik, M., Self, A., Birks, H. J. B. & Brooks, S. J. 2011: Chironomidae (Insecta: Diptera) succession in Żabieniec bog and its palaeo-lake (central Poland) through the Late Weichselian and Holocene. Palaeogeography, Palaeoclimatology, Palaeoecology 307, 150–167.

[61] Pochocka-Szwarc, K. 2013: Some aspects of the last glaciations in the Mazury Lake District (north-eastern Poland). Acta Palaeobotanica 53, 3–8.

[62] Quinlan, R. & Smol, J. P. 2001: Chironomid-based inference models for estimating end-of-summer hypolimnetic oxygen from south-central Ontario shield lakes. Freshwater Biology 46, 1529–1551.

[63] Rach, O., Brauer, A., Wilkes, H. & Sachse, D. 2014: Delayed hydrological response to Greenland cooling at the onset of the Younger Dryas in western Europe. Nature Geoscience 7, 109–112.

[64] Reavie, E. D., Sgro, G. V., Estepp, L. R., Bramburger, A. J., Shaw Chraibi, V., Pillsbury, R. W., Cai, M., Stow, C. A. & Dove, A. 2017: Climate warming and changes in Cyclotella sensu lato in the Laurentian Great Lakes. Limnology and Oceanography 62, 768–783.

[65] Rohling, E. J. & Pälike, H. 2005: Centennial-scale climate cooling with a sudden cold event around 8200 year ago. Nature 434, 975–979.

[66] Schwander, J., Eicher, U. & Ammann, B. 2000: Oxygen isotopes of lake marl at Gerzensee and Leysin (Switzerland), covering the Younger Dryas and two minor oscillations, and their correlation to the GRIP ice core. Palaeogeography, Palaeoclimatology, Palaeoecology 159, 203–214.

[67] Šeirien≐, V., Stančikait≐, M., Kisielien≐, D. & Šinkūnas, P. 2006: Lateglacial environment inferred from palaeobotanical and 14C data of sediment sequence from Lake Kašuciai, West Lithuania. Baltica 19, 80–90.

[68] Seppä, H. & Poska, A. 2004: Holocene annual mean temperature changes in Estonia and their relationship to solar insolation and atmospheric circulation patterns. Quaternary Research 61, 22–31.

[69] Seppä, H., Birks, H. H. & Birks, H. J. B. 2002: Rapid climatic changes during the Greenland stadial 1 (Younger Dryas) to early Holocene transition on the Norwegian Barents Sea coast. Boreas 31, 215–225.

[70] Spötl, C. & Vennemann, T. W. 2003: Continuous-flow isotope ratio mass spectrometric analysis of carbonate minerals. Rapid Communications in Mass Spectrometry 17, 1004–1006.

[71] Stančikait≐, M., Gedminien≐, L., Edvardsson, J., Stoffel, M., Corona, C., Gryguc, G., Uogintas, D., Zinkut≐, R., Skuratovič, Ž. & Taraškevičius, R. 2019: Holocene vegetation and hydroclimatic dynamics in SE Lithuania-Implications from a multi-proxy study of the Čepkeliai bog. Quaternary International 501, 219–239.

[72] Stančikait≐, M., Kisielien≐, D., Moe, D. & Vaikutien≐, G. 2009: Lateglacial and early Holocene environmental changes in northeastern Lithuania. Quaternary International 207, 80–92.

[73] Stančikait≐, M., Šeirien≐, V., Kisielien≐, D., Martma, T., Gryguc, G., Zinkut≐, R., Mažeika, J. & Šinkūnas, P. 2015: Lateglacial and early Holocene environmental dynamics in northern Lithuania: a multi-proxy record from Ginkūnai Lake. Quaternary International 357, 44–57.

[74] Stančikait≐, M., Šinkūnas, P., Šeirien≐, V. & Kisielien≐, D. 2008: Patterns and chronology of the Lateglacial environmental development at Pamerkiai and Kašučiai, Lithuania. Quaternary Science Reviews 27, 127–147.

[75] Stivrins, N., Soininen, J., Amon, L., Fontana, S., Gryguc, G., Heikkilä, M., Heiri, O., Kisielien≐, D., Reitalu, T., Stančikait≐, M., Veski, S. & Seppä, H. 2016: Biotic turnover rates during the Pleistocene-Holocene transition. Quaternary Science Reviews 151, 100–110.

[76] Stuiver, M., Grootes, P. & Braziunas, T. 1995: The GISP2 (δ O) climate record of the past 16,500 years and the role of sun, ocean, and volcanoes. Quaternary Research 44, 341–354.

[77] Ter Braak, C. J. F. & Šmilauer, P. 2002: CANOCO Reference Manual and CanoDraw for Windows User's Guide: Software for Canonical Community Ordination (Version 4.5). Ithaca, New York.

[78] Van Asch, N., Kloos, M., Heiri, O., De Klerk, P. & Hoek, W. 2012: The Younger Dryas cooling in northeast Germany: summer temperature and environmental changes in the Friedländer Große Wiese region. Journal of Quaternary Science 27, 531–543.

[79] Van Dam, H., Mertens, A. & Sinkeldam, J. 1994: A coded checklist and ecological indicator values of freshwater diatoms from the Netherlands. Netherlands Journal of Aquatic Ecology 28, 117–133.

[80] Velle, G., Brooks, S. J., Birks, H. J. B. & Willasen, E. 2005: Chironomids as a tool for inferring Holocene climate: an assessment based on six sites in southern Scandinavia. Quaternary Science Reviews 24, 1429–1462.

[81] Veski, S., Seppä, H., Stančikait≐, M., Zernitskaya, V., Reitalu, T., Gryguc, G., Heinsalu, A., Stivrins, N., Amon, L., Vassiljev, J. & Heiri, O. 2015: Quantitative summer and winter temperature reconstructions from pollen and chironomid data between 15 and 8 ka BP in the Baltic-Belarus area. Quaternary International 388, 4–11.

[82] Wachnik, A. 2009: Vegetation development in the Lake Miłkowskie area, north-eastern Poland, from the Plenivistulian to the late Holocene. Acta Palaeobotanica 49, 287–335.

[83] Watson, J., Brooks, S. J., Whitehouse, N. J., Reimer, P. J., Birks, H. J. B. & Turney, C. 2010: Chironomid-inferred Lateglacial summer air temperatures from Lough Nadourcan, Co., Donegal, Ireland. Journal of Quaternary Science 25, 1200–1210.

[84] Wiederholm, T. 1983: Chironomidae of the Holarctic region. Keys and diagnoses. Part 1. Larvae. 67. Entomologica Scandinavica 457, pp.

[85] Yu, Z. & Eicher, U. 2001: Three amphi-Atlantic century-scale cold events during the Bølling-Allerød warm period. Géographie physique et Quaternaire 55, 171–179.

[86] Zernitskaya, V., Stančikait≐, M., Vlasov, B., Šeirien≐, V., Kisielien≐, D., Gryguc, G. & Skipityt≐, R. 2015: Vegetation pattern and sedimentation changes in the context of the Lateglacial climatic events: case study of Staroje Lake (Eastern Belarus). Quaternary International 386, 70–82.

[87] Zha, X. P., Zhao, Y. Y. & Zheng, Y. F. 2010: An online method combining a Gasbench II with continuous flow isotope ratio mass spectrometry to determine the content and isotopic compositions of minor amounts of carbonate in silicate rocks. Rapid Communications in Mass Spectrometry 24, 2217–2226.