VILNIUS UNIVERSITY
NATURE RESEARCH CENTRE

GRAŽYNA GRYGUC

PECULIARITIES OF VEGETATION CHANGES RECORDED IN LATE GLACIAL AND HOLOCENE SEDIMENTS ACCORDING TO PALAEOBOTANICAL DATA.

Summary of Doctoral Dissertation
Physical sciences, Geology (05 P)

Vilnius, 2015

The dissertation was prepared at the Nature Research Centre, Institute of Geology and Geography in 2011–2014.

Scientific supervisor - dr. Dalia Kisielienė (Nature Research Centre, Institute of Geology and Geography, Physical sciences, Geology – 05 P)

The dissertation is defended at the Council of Geology Research of Vilnius University:

***Chairman* -** prof. dr. Albertas Bitinas (Klaipėda University, Physical Sciences, Geology – 05 P)

Members:
Assoc. prof. dr. Julius Taminskas (Nature Research Centre, Physical Sciences, Geography – 06 P),
Dr. Gražina Skridlaitė (Nature Research Centre, Physical Sciences, Geology – 05 P),
Prof. dr. hab. Małgorzata Latałowa (Gdansk University, Poland, Biomedical Sciences, Biology – 01 B),
Dr. Jurga Motiejūnaitė (Nature Research Centre, Biomedical Sciences, Biology – 01 B).

The official defence of the dissertation is due to be held at the public meeting of the Physical Science Council at the Nature Research Centre, Institute of Geology and Geography on 27 March 2015, at 2 p.m.
Address: Akademijos Str. 2, LT-08412, Vilnius, Lithuania.

The summary of the dissertation was distributed on February 26, 2015
The dissertation is available in the libraries of Vilnius University and Nature Research Centre, Institute of Geology and Geography and online: *www.vu.lt/lt/naujienos/ivykiu-kalendorius*

VILNIAUS UNIVERSITETAS

GAMTOS TYRIMŲ CENTRAS

GRAŽYNA GRYGUC

VĖLYVOJO LEDYNMEČIO IR HOLOCENO AUGALIJOS RAIDOS YPATUMAI NUOSĖDŲ PALEOBOTANINIŲ TYRIMŲ DUOMENIMIS

Daktaro disertacijos santrauka

Fiziniai mokslai, geologija (05 P)

Vilnius, 2015

Disertacija rengta 2011–2014 metais Gamtos tyrimų centre, Geologijos ir geografijos institute.

Mokslinis vadovas – dr. Dalia Kisielienė (Gamtos tyrimų centras, fiziniai mokslai, geologija – 05 P)

Disertacija ginama Vilniaus universiteto Geologijos mokslo krypties taryboje:

***Pirmininkas* –** prof. dr. Albertas Bitinas (Klaipėdos universitetas, fiziniai mokslai, geologija – 05 P).

Nariai:

Doc. dr. Julius Taminskas (Gamtos tyrimų centras, fiziniai mokslai, geografija – 06 P),

Dr. Gražina Skridlaitė (Gamtos tyrimų centras, fiziniai mokslai, geologija – 05 P),

Prof. habil. dr. Małgorzata Latałowa (Gdansko universitetas, Lenkija, biomedicinos mokslai, biologija – 01B),

Dr. Jurga Motiejūnaitė (Gamtos tyrimų centras, biomedicinos mokslai, biologija – 01B).

Disertacija bus ginama viešame Geologijos mokslo krypties tarybos posėdyje 2015 m. kovo mėn. 27 d., 14.00 val. Gamtos tyrimų centro salėje, Akademijos g. 2, LT-08412, Vilnius, Lietuva.

Disertacijos santrauka išsiųsta 2015 m. vasario mėn. 26 d.

Su disertacija galima susipažinti Vilniaus universiteto, Gamtos tyrimų centro Geologijos ir geografijos instituto bibliotekose ir VU interneto svetainėje adresu: *www.vu.lt/lt/naujienos/ivykiu-kalendorius*

INTRODUCTION

PROBLEMATICS

Majority of investigations on the Lateglacial and Holocene palaeoenvironments in Lithuania were based on the palynological analysis alone. The only vegetation dynamics was studied because of limitations of the above method. In order to fill up the gap, the plant macrofossils were investigated. The latter investigations allow better reconstruction of conditions of local environments, climatic indicators, palaeobasin evolution, as well as the migration of distinct plant species. There is still an urgent need, especially in Lithuania, for results of the plant macrofossil investigations supported with isotopic age datings. These results are crucial for the understanding of the evolution of the Lateglacial and Holocene vegetation.

TOPICS

Investigations of plant macrofossils are necessary for a reconstruction of palaeoenvironmental conditions because they allow better understanding of climatic, hydrologic, soil-forming and biotic palaeoenvironmental changes in the Lateglacial and Holocene. The earlier applied methods did not allow such a detail reconstruction of the palaeoenvironmental conditions. Moreover, an application of the plant macrofossil investigations allowed better reconstruction of the distribution of vegetation cover in a particular area, immigration of particular taxa, and identification of a variety of plant species. The investigation results helped to obtain an evolution of water basins as well as their surroundings. The age datings of plant macrofossils by the AMS method not only allowed better timing of the studied sedimentation periods but also the correlation of the defined climatic events with the well-known global and regional ones.

AIM OF THE STUDY

To decipher the vegetation evolution in the Lateglacial and Holocene based on multiproxy approach.

TASKS

1. To analyse the plant macrofossils records in the sections of marshy-lacustrine sediments.
2. To characterise the local vegetation and its evolution by means of the plant macrofossil survey.
3. To define plant palaeocommunities, that formed during the particular events of palaeobasin evolution.
4. To characterize ecological conditions of plant habitats in the studied areas on the basis of the Ellenberg's system widely used for the evaluation of modern environmental conditions.
5. To reconstruct palaeoenvironments and to track their history in the Lateglacial and Holocene according to the obtained results of multiproxy investigations.

THE STATEMENTS TO BE DEFENDED

1. The plant palaeocommunities outlined in the investigated sediment cores provide basic information on dominating plant types and evolution of palaeocommunities during the particular post-glacial periods.

2. The Ellenberg system of the evaluation of modern environmental conditions is suitable for the evaluation of palaeoenvironmental conditions and the reconstruction of ecological conditions of plant habitats during the Lateglacial and Holocene.

3. Lateglacial, short-lived climatic events can be defined not only by typical vegetation transformations but also by distinct indicator species.

4. Typical post-glacial vegetation communities can provide information on distinct stages of water basin evolution.

SCIENTIFIC NOVELTY

1. Until now the Lateglacial and Holocene sediments in Lithuania were poorly investigated by means of a plant macrofossil analysis, thus the above method was widely applied for those sediments in this study for the first time.

2. An analysis of wet palaeobotanic matter was used for the first time in Lithuania for an extraction of plant macrofossils from sediments, which allowed identification of a wider range of plant variety, i.e. particular plant speciments and their groups.

3. For the sedimentation chronology of the studied sections, a dating of plant macrofossils (seeds, fruits) was applied in addition to a conventional dating of organic-carbonatic sediments. The dated tree (*Pinus*, *Alnus glutinosa*) macrofossils added a new value to the reconstruction of chronological sequences and evaluation of the vegetation expansion history.

4. The Ellenberg chart (Ellenberg et al., 1991) was applied for the reconstruction of ecological conditions of palaeoecosystems in Lithuania for the first time.

5. The plant palaeocommunities of the Lateglacial and Holocene were revealed by means of the plant macrofossil analysis for the first time in Lithuania.

IMPORTANCE OF THE STUDY

The investigation of plant macrofossils carried out by the author supplied the Lithuanian databases with a new data on vegetation and its history in the post-glacial time. The obtained results enabled dating of the immigration of some plant species into the study area. The new information will help to solve not only stratigraphy and palaeoecology problems but also provide a possibility to reconstruct climatic changes. The integrated approach used in the study allowed better understanding and detail reconstruction of vegetation and palaeoecological changes during the Lateglacial and Holocene as well as assessment of the evolution of marshy and lacustrine sedimentary basins.

PREPARATION

The author entered the Joint Doctoral Study of Vilnius University and Nature Research Centre in 2011. At the beginning, the author got acquainted with basics of sampling, sample preparation and plant macrofossil analysis. The knowledge gained at the Institute of Geology and Geography of Nature Research Centre (IGG NRC) was enhanced during the study in Poland (Gdańsk University), Finland (Helsinki University) and Estonia (Tallinn Technical University). Later, the author dealt with the problems of vegetation and environmental changes in the Lateglacial and Holocene. As a staff-member of the Laboratory of Quaternary Research the author participated in the national and international projects such as international project *Biotic Response to Climate Change in Cold Climates (BioCold)*, national science programmes *The Effect of Anthropogenic Factors on the Development of Invasive Species in Holocene in the Context of Development of Palaeoecosistem* (LEK-02/2010), and *Expansion of palaeovegetation in context of the postglacial ecosystem dynamics in the Eastern Baltic* (LEK-08/2012). The participation in the above projects helped to obtain materials for this study and to apply other analytical methods. For this study, the 7 sedimentary sections were analysed. The author analysed the 781 plant macrofossils, 86 pollen and 356 LOI (loss-on-ignition) samples.

APPROBATION

The obtained results were presented at the 9 international (Poland, Estonia, the Netherlands, Sweden, Greece, Russia and Lithuania), and 2 national (Lithuania) conferences. The 5 scientific publications prepared with co-authors during the study were published or accepted for publication in the journals with CI included in the ISI WOS database.

CONTENTS

The thesis consists of Introduction, a review of the previous studies, stratigraphy of the post-glacial sediments**,** site description, methodology and presentation of the obtained results, discussion, conclusions, reference list and appendices. The 22 figures and 35 tables are presented in the study. The thesis comprises 182 pages. The thesis is supplied with 10 appendices (1-10) given at the end of the thesis.

ACKNOWLEDGEMENTS

I would like to thank all the employeers at the laboratory of Quaternary Research, Institute of Geology and Geography, Nature Research Centre, who helped me with the thesis preparation. Special thanks are to my supervisor Dr. D. Kisielienė for her help with methodics, valuable remarks and advices. I'm grateful to Dr. M. Stančikaitė and Dr. V. Šeirienė who kindly supported me with the data, and doctoral student R. Skipitytė who provided me with the isotopic estimations. I appreciate the help of Prof. J. Mažeika and Colleagues from the Laboratory of Nuclear Geophysics and Radioecology with radioisotope investigations. For advices how to prepare samples for a plant macrofossil analysis I am grateful to Mrs. J. Vaitkevičienė. I also thank Mrs. L. Statkūnienė for a palynological sample preparation. Many thanks go to Prof. M. Latałowa (Gdańsk University) and Dr. M. Väliranta (Helsinki University) for their valuable advices during my traineeships. I highly appreciate any help provided during my study. I thank so much my cordial friend Alius, my parents, relatives and friends for their support, patience and understanding.

The study was partly supported by the Lithuanina Research Council (National Science programmes N LEK-08/2012 and LEK-02/2010; international programmes ES COST (Action ES0907); BioCOLD; Financial support for Doctoral studies N DOK-13259 and DOK-14316).

1. REVIEW OF THE PREVIOUS STUDIES

Investigations of plant macrofossil started in the 19th century (cf. Birks, 2001). An analysis of plant macrofossils was widely used for an investigation of Quaternary sediments at that time. The approach was introduced by Clement and Eleanor Mary Reid, who studied remains of seeds and fruits in the Quaternary sediments of the British Isles, later of Germany and Denmark. The obtained results were presented in the book „The Origin of the British Flora“ published in 1899, where the evolution of Quaternary environments in Western Europe is presented (Reid, 1899).

A plant macrofossil analysis in Russia started in the early 20th century. V. N. Suka Sukachev was the first who used the method for studies of a fossil flora (Сукачев, 1910, 1938). The most important were the studies of P. A. Nikitin (Никитин 1957, 1965). He is considered to be an initiator of a palaeocarpology science in the former Soviet Union. He studied a wide range of a fossil flora: from Paleogene to Neo-Pleistocene and Holocene. Similar studies were carried out by P. I. Dorofeyev (Дорофеев, 1966, 1986), F. J. Velichkyevich (Величкевич, 1982) etc.

An analysis of plant macrofossils was initiated in Poland in the fifties of 20th century. One of the first initiators was Polish palaeobotanist Prof. W. Szafer. He studied the Pliocene and Pleistocene flora (Szafer, 1954). The fossil flora was later investigated by J. Raniecka-Bobrowska (1962), M. Łańcucka-Środoniowa (1963) etc. In 1958, the Polish scientist S. Tołpa introduced a plant macrofossil approach into phyto-sociological investigations. He was the first who described how to use the phyto-sociological method for a reconstruction of ancient plant communities (Tołpa, 1958). S. Tołpa together with M. Jasnowski and A. Pałczyński used the approach for a genetic classification of marshes (Tołpa et al., 1967). A term „palaeophytosociology“ was introduced by A. Pałczyński (Pałczyński, 1975) in 1975, and was later used by H. H. Birks and H. J. B. Birks (1980). Similar investigations were carried out also in Middle Europe (Rybniček, 1973).

In Sweden, plant macrofossils were studied by a palaeobotanist A. G. Nathorst (Nathorst, 1870) and the major part of the data obtained served a basis for modern Quaternary vegetation geography (cf. Birks, 2014).

In 1891, an Estonian geologist F. Shmidt together with Swedish geologists A. G. Nathorst and N. O. Holst, discovered plant macrofossils of the Arctic flora (*Salix polaris*, *S. herbacea*, *Salix reticulata, Dryas octopetala*, *Polygonum viviparum*, *Betula nana*) in the Lateglacial sediments in northern Estonia (Amon, 2011). The obtained results were used for a stratigraphic subdivision of sediments and investigations of palaeoecological changes during the distinct post-glacial periods. Similar investigations were carried out later by K. Jessen and W. A. Watts (Ireland), H. Godwin (Great Britain), G. Lang (Central Europe), W. A. Watts, H. H. Birks, and N. G. Miller (central and eastern South America) (Birks, 2008; Birks, 2014).

The Estonian palynologist P. W. Thomson used the plant macrofossil approach for Lateglacial sediments in Lithuania and discovered the Allerød moss remains (Thomson, 1931). Later, P. W. Thomson studied the Kunda river sediments in northern Estonia and discovered the spruce wood assigned to the Lateglacial time (Amon, 2011).

Until the sixties, a pollen analysis was preferred for palaeoenvironmental reconstructions. Then, the plant macrofossil approach was re-discovered and established for the Lateglacial and Holocene environmental reconstructions. B. Watts with colleagues applied the method for their studies in North America. H. H. Birks introduced the method of plant macrofossil survey in Europe. She introduced an integrated approach when pollen, molluscs, diatoms as well as sediment chemistry and lithology have been studied along with the plant macrofossil. Moreover, H. H. Birks elaborated the methodology of a standard plant macrofossil analysis, where sampling techniques, sample preparation, analysis and possible interpretations were described (Birks, 2001). The problems of sample distribution, preservation and recovery were described in Birks (1973) and Watts (1978) publications.

In Lithuania, the plant macrofossil method was firstly applied to the inter-glacial sediments. However, the first plant macrofossil studies in Lithuania in late 19th and early 20th centuries were sparse and fragmented. Only later, its application for the Lateglacial and Holocene investigations was considered. The first plant macrofossilsin Lithuania were mentioned by foreign scientists A. Jentzsch (1878), N. N. Sobolev (Соболев, 1910), H. Preuss (1910) and C. Weber (Weber, 1902).

Later, the plant macrofossil investigations in Lithuania were outlined by the Polish scientists: B. Halicki, T. Urbanski (1936), B. Halicki (1949, 1951), A. Środoń (1950), M. Brem, and M. Sobolewska (1950). From the second half of 20^{th} century, the plant macrofossil approach in Lithuania was widely used by M. Riškienė. She applied the method for the Lithuanian inter-glacial sediments (Ришкене 1967, 1973, 1974, 1976, 1979). The Belarusian scientists F. Velichkevich (Величкевич 1975, 1979, 1980) and G. Litvinyuk (Литвинюк, 1981) also investigated plant macrofossils in the Lithuanian sediments. All these investigations helped to solve problems of stratigraphy and palaeogeography of the Quaternary in Lithuania.

Dr. Dalia Kisielienė continues the M. Riškienė's plant macrofossil investigations. She has studied Pleistocene and Holocene plant remains in the Quaternary sediments of Lithuania. Her studies provided a lot of information on stratigraphy and palaeogeography of the region. In her doctoral thesis of 2002, D. Kisielienė described those Quaternary stratigraphic subdivisions for which a plant macrofossil analysis had been carried out. The newly established palaeocarpological complexes and their regional correlation were also given in the thesis (Kisielienė, 2002). D. Kisielienė started to apply the plant macrofossil analysis for the Lateglacial and Holocene sediments in Lithuania (Kisielienė, 2002).

During the last decades, the method is broadly applied for palaeoenvironmental reconstructions of the Lateglacial and Holocene (Lotter, 1999; Birks and Birks, 2000; Birks 2001, 2007; Väliranta et al., 2006; Wohlfarth et al., 2006; Saarse et al., 2009; Amon et al., 2010), as well as for characteristics of local vegetation and its evolution in different water basins and marshes (Hannon and Gillard, 1997; Birks, 2000; Tobolski, 2000; Birks and Birks, 2006; Väliranta, 2006; Gałka and Sznel, 2013, Gałka, 2014).

The method is recognized by many scientists as one of the major studies for palaeoecological conditions (Hannon and Gaillard, 1997; Lotter, 1999; Birks and Wright, 2000, Birks, 2001; Punning et al., 2005; Dieffenbacher-Krall & Nurse, 2005; Väliranta et al., 2005; Väliranta, 2006; Bos et al., 2006; Gałka et al., 2014). The method is widely used for palaeoecological investigations of distinct species of vegetation (Gałka et al., 2012; Gałka, Tobolski, 2012, 2013).

Nowadays, the plant macrofossil investigations are often coupled with isotopic estimations (AMS datings) in order to decipher precise stratigraphy of sediments and vegetation variety in the study area (Bos et al., 2006; Gałka and Tobolski, 2013; Karpińska-Kołaczek et al., 2013).

The plant macrofossil analysis often becomes a part of multiproxy investigations. The integrated approach allows more detail characteristics of vegetation evolution, better establishment of sedimentation processes and palaeoclimatic changes, and better reconstruction of vegetation expansion in the Lateglacial and Holocene (Birks and Birks, 2006; Amon et al., 2010; Väliranta et al., 2011; Gałka et al., 2014). Similar investigations appeared recently also in Lithuania (Stančikaitė et al., 2008, 2009; Gaidamavičius et al, 2011, Gryguc et al., 2013), however plant macrofossil studies are still required in order to establish the post-glacial vegetation history in detail.

Meantime, the plant macrofossils have been studied for archaeology purposes. By means of that approach, the nutrition of our ancestors, as well as their economic activities and living environments during the distinct pre-historic and historic periods can be reconstructed (Kisielienė et al., 2008; Kisielienė, 2013). A reliable information on interaction of humans and their natural surroundings in the past can be implied from the plant macrofossil investigations coupled with palynologic and radio-isotopic estimations.

2. STRATIGRAPHY OF THE POST-GLACIAL SEDIMENTS

In Europe, Iversen (1954) suggested post-glacial sediment subdivision based on biostratigraphy and chronostratigraphy, which was later improved by Mangerud et al. (1974), who invented a transgression of chronological boundaries. Later, Björck in co-operation with other scientists (1998) defined the climatic episodes of the post-glacial time correlated with the isotopic fluctuations in the cross-sections of the Greenland icecap, comprising an interval of 23–11 cal yr BP. In 2008, J. J. Lowe and other scientists defined more precise chronological boundaries for the above episodes (Table 1) and expanded a time interval (0 – 30 cal yr BP; Lowe et al., 2008).

Table 1. Postaglacial climatic events and chronology line by Lowe et al., 2008.

Climatic events	Calibrated age (cal. yr. BP)	Chronozones
GS-1	~11 650–12 850	Younger Dryas
GI-1a	~12 850–13 050	Allerød
GI-1b	~13 050–13 250	Gerzensee oscillation
GI-1c	~13 250–13 900	Allerød
GI-1d	~13 900–14 050	Older Dryas
GI-1e	~14 050–14 650	Bølling

The Holocene subdivision was more complicated because climatic and palaeoenvironmental changes were less prominent at that time when in the Lateglacial. The scientists of INTIMATE group proposed two major subdivisions for the Holocene based on the fluctuations in the Greenland ice cross-sections: the first between early and middle (8200 cal yr BP), and the second between middle and late (4200 cal yr BP) Holocene.

In order to correlate the previous investigations in Lithuania and Europe in this study, the stratigraphic chart for the Lateglacial and Holocene in Lithuania (Kabailienė, 2006) was compared to the chart for climatic events by Lowe et al. (2008) and Walker et al. (2012). The combined chart was used by the author for stratigraphic interpretation of the obtained results.

3. THE STUDY OBJECTS

The 7 objects were chosen for investigations: four Lakes (Briaunis, Verpstinis, Pakampis, Pakastuva), one marsh (Lavariškės) and two outcrops of the palaeobasin sediments at Ūla river (Zervynai, Rudnia). The study objects are situated in southeastern, eastern and northwestern Lithuania (Fig.1, Table 2). The study objects are situated in glaciofluvial lowlands and moraine uplands of the Last (Weichselian) Glaciation.

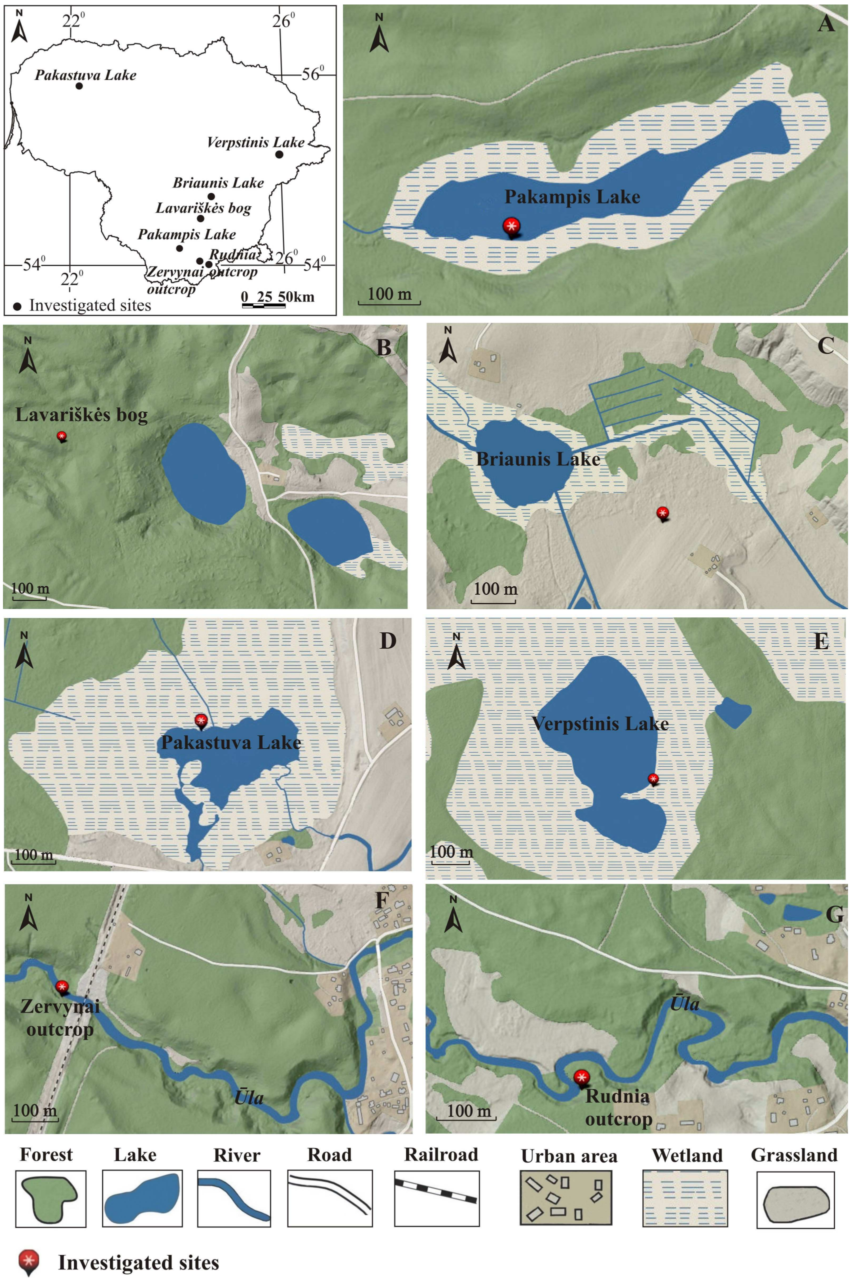

Fig. 1. Location of study sites.

4. NATURAL ENVIRONMENT

A term "natural environment" is usually understood as a whole of natural inter-related components, and their unifying natural and anthropogenic systems. Major biotic natural components are plant and animal lives, while abiotic comprise climate, soil, water, surface etc (Bukantis et al., 2008). The plant life is important for its immediate reaction to climatic changes and human activities. Thus, the plant variety and evolution are good indicators of environmental changes. The modern natural environment and its components are a key for understanding of environmental changes in our past. Therefore climatic conditions, vegetation types, and soil variety have to be described for the study areas.

5. METHODS OF INVESTIGATIONS

5.1. Drilling and sediment sampling

In the field, sediment samples were collected from outcrop walls and by drilling in places where they were covered. The concealed sediments were sampled by the "Russian" manual drill with a chamber 1 m long and 5 cm in diameter. Monolithic sections were cut from the outcropping sediments. Sediment lithology, colour, homogeneity, layer boundaries and other properties were described at the sampling site. The 2–5 cm long sections were sampled for a plant macrofossil analysis and datings (^{14}C, AMS), while 2 cm long sections were used for pollen-spore, isotopic ($\delta^{18}O$ ir $\delta^{13}C$) and lithologic (LOI) investigations (Table 2).

Table 2. The analytical methods applied and number of sample analysed.

No.	Study Sites	Coordinates	Analyses					Sediment thickness, cm
			Pollen	Plant macrofossil	Loss-on-ignition	Radiocarbon (^{14}C, AMS) dating	Isotope ($\delta^{18}O$, ^{13}C) survey	
Lakes								
1.	Briaunis	54°43'06"N 24°36'20"E	42	150	46	8	-	800

2.	Verpstinis	55°11’38,2“N 25°52’26,9“E	35	113	120	6	-	600
3.	Pakampis	54°11'01,29"N 24°08'24,30"E	45	204	190	4	-	950
4.	Pakastuva	56°4’13,23“N 21°51‘6,63“E	48	108	-	5	-	630
Bog								
5.	Lavariškės	54°37‘4,60“N 24°30‘9,65“E	74	170	-	5	-	1000
Outcrops								
6.	Zervynos	54°06´30"N 24°29´08"E	89	34	89	5	58	177
7.	Rudnia	54°04´07,9"N 24°39´35,4"E	39	34	39	4	-	77

5.2. Analysis of plant macrofossils

Sample preparation in the laboratory

The sampled in field sediments underwent a laboratory treatment for further investigations. Sample volumes have been calculated, and the samples prepared for rinsing. In case of a very compact, resistant to rinsing sample, it was kept for awhile in water or weak soda solution (2g/l of calcic soda (Na_2CO_3) or drinkable soda ($NaHCO_3$) dissolved in water). The sediments were heated in the weak soda solution if needed. After the sediments had weakened, they were carefully rinsed by tap water through a 0.2 mm dense sieve. When fine-grained mineral and organic particles had been washed out, the remaining matter was removed from the sieve, placed into vessels and poured over with distilled water. The prepared samples can be stored in a refrigerator and used for further microscopic analysis.

Microscopic analysis

For a microscopic analysis, the matter was removed from the vessels, placed on the *Petri* plate, and poured over with distilled water in order to distribute it on the plate evenly. The prepared sample was thoroughly studied under a binocular stereo-microscope using magnification of 10–100X. The plant macrofossils were removed by tweezers and identified according to Beijerinck (1947), Cappers et al. (2006) and Grigas (1986) atlases and the modern plant collections. The identified macrofossils were calculated, and the obtained data in turn re-calculated for a volume unit (cm^3). Such re-calculation is necessary in order to correlate the obtained data from different places.

Data treatment and visualisation

The computer programmes *Tilia* (2 version), *Tilia graph* (2.0 5b version) (Grimm, 1992) and CorelDRAW 7 were used for further data treatment and visualization of all data obtained. On the basis of the cluster analysis (CONISS) (Grimm, 1987), complexes of macro-flora were subdivided into local macrofossil zones (LMZ) and the same method was used working with pollen and diatom data. The results of all palaeobotanical investigations are presented on diagrams by numbers, histograms or signs.

On the basis of the studied plant macrofossils, several complexes of plant palaeocommunities were revealed. A plant community usually forms as a result of certain ecological conditions and relationships between the existing species. It is important to define such palaeocommunities in order to understand what types of habitats existed in the past, and in what ecological conditions those habitats thrived. Descriptions of modern plant communities were referred to. The identified plant macrofossil species were compared to the species assigned to distinct modern habitats in the modern plant classification chart. According to these characteristic species which usually thrive in a community of certain type (Tupčiauskaitė, 2012), the plant palaeocommunities were identified.

The Ellenberg chart for the modern Middle Europe vegetation (Ellenberg et al., 1991) was used to decipher in what environmental conditions the defined palaeocommunities had been formed. The 5 major ecological indicators, i.e. climatic (temperature) and local (light, soil dumpiness, pH reaction and nitrogen content), were used for the evaluation of environmental conditions in which the plant species identified from the studied plant macrofossils had lived. The plant tolerance for each indicator is given in numbers or symbols. The light, temperature, pH reaction and nitrogen content indicators are presented in a scale of nine, while the dumpiness indicator has units from

1 to 12, where 1 is the weakest and 12 is the strongest tolerance for the ecological indicator. Means of ecological indicator values for water and land habitats are presented in the tables (excluding x values showing that a certain plant does not express any tolerance for the indicator). The system enables characterisation of plant species, plant communities and even environmental conditions of habitats (Ulevičius and Tupčiauskaitė, 2013).

In the thesis, the nomenclature of Z. Gudžinskas (1999) was used for plant identification.

5.3. Other methods of investigations

5.3.1. Loss-on-ignition (LOI)

Estimations of the sediment composition (LOI) were applied for the evaluation of sedimentation processes during the distinct post-glacial periods. The estimations were carried out using the standard methodics described by Bengtsson and Enell (1986), and Gedda (2001).

5.3.2. Pollen investigations

These investigations are most important for reconstruction of post-glacial vegetation and history. The plant macrofossil and pollen survey methods are highly compatible therefore the results obtained by each method can strengthen the implications. The samples for a palynological analysis were prepared at the Laboratory of Quaternary Research, Institute of Geology and Geography, Nature Research Centre.

For a pollen extraction the separation method of V. Grichuk (Grichuk, 1940) and acetolysis method of G. Erdman (Erdtman, 1936) were applied. Spore and pollen concentration in the sediments was calculated using *Lycopodium clavatum* (Stockmarr, 1971). 500 pollen grains of terrestrial plants were counted in each sample. The atlases of Fægri and Iversen (1989), Moe (1974) and Moore et al. (1991) have been used for the identification of the speciments discovered. Percentage calculation of identified taxa is based on the sum of arboreal ΣAP plus non- arboreal ΣNAP taxa.

5.3.4. Radiocarbon (^{14}C, AMS) dating

A radiocarbon method (^{14}C, AMS) has been applied in order to date the studied sediments and to compile independent chronology charts.

The collected sediment samples have been dated by methods of: radioactive carbon (^{14}C) at the Laboratory Nuclear Geophysics and Radioecology, Institute of Geology and Geography, Nature Research Centre (laboratory numbers starting with Vs-), at the Radiocarbon Laboratory in Kyiv (laboratory numbers starting with Ki-), at the Radiocarbon laboratory of Florida Beta Analytics (laboratory numbers starting with Beta-); and Accelerator Mass Spectrometry (AMS) at the Radiocarbon laboratory of Poznań (laboratory numbers starting with Poz-). For the data calibration, the programme OxCal v3.10 (Bronk and Ramsey, 2001) and calibration curve IntCal2009 (Reimer et al, 2013) were used. The obtained ages and chronology charts are given in calibrated years before present (cal yr BP).

5.3.5. Isotopic ($\delta^{18}O$ and $\delta^{13}C$) investigations

Isotopic ($\delta^{18}O$ and $\delta^{13}C$) investigations are usually applied for a study of climatic changes in palaeoenvironments, i.e. temperature and dumpiness fluctuations. Such investigations were carried out at the Centre for Physical Sciences and Technology in Vilnius by a doctoral student Raminta Skipitytė. A ratio of stable carbon and oxygen isotopes was obtained from the carbonate matter using Debajyoti and Skrzypek (2007) methodics. The obtained isotope values were correlated with the isotopic data from the Greenland ice sections (NGRIP) (Andersen et al., 2004). The defined fluctuations allowed the author to reconstruct chronological boundaries and to correlate identified environmental fluctuations.

6. THE STUDY RESULTS

The results obtained by author during the study are presented in this chapter i.e. the results on lithology conditions implied from the LOI estimations; on vegetation variety and evolution provided by the pollen and plant macrofossil estimations; on climatic changes obtained from the isotopic investigations ($\delta^{18}O$ ir $\delta^{13}C$) and pollen based reconstructions of summer and winter temperatures; on chronology (^{14}C studies) and sedimentation of the cores are described and presented in tables and diagrams. The results of plant macrofossil analysis plays the leading role in above mentioned investigations. The detailed overwie of the multiproxy data used for the reconstruction of the post-glacial vegetation and environmental history is given in the articles published i.e.

Veski, S., Seppa, H., Stančikaitė, M., Zernitskaya, V., Reitalu, T., ***Gryguc, G****., Heinsalu, A., Stivrins, N., Amon, L., Vassiljev, J., Heiri, O. 2014. Quantitative summer and winter temperature reconstructions from pollen and chironomid data between 15 and 8 ka BP in the Baltic–Belarus area. Quaternary International. doi:10.1016/j.quaint.2014.10.059*

Zernitskaya V., Stančikaite M., Vlasov B., Šeiriene V., Kisieliene D., ***Gryguc G.****, Skipityte R. 2014. Vegetation pattern and sedimentation changes in the context of the Lateglacial climatic events: Case study of Staroje Lake (Eastern Belarus). Quaternary International. DOI: 10.1016/j.quaint.2014.06.045*

Stančikaitė M., Šeirienė V., Kisielienė D., Martma T., ***Gryguc G.****, Zinkutė R., Mažeika J., Šinkūnas P. 2014. Lateglacial and early Holocene environmental dynamics in northern Lithuania: A multi-proxy record from Ginkūnai Lake. Quaternary International. DOI http://dx.doi.org/10.1016/j.quaint.2014.08.036*

Gryguc G.*, Kisielienė D., Stančikaitė M., Šeirienė V., Skuratovič Ž., Vaitkevičius V., Gaidamavičius A. 2013. Holocene sediment record from Briaunis palaeolake, Eastern Lithuania: history of sedimentary environment and vegetation dynamics. Baltica. 26 (2): 121–136.*

Gaidamavičius A., Stančikaitė M., Kisielienė D., Mažeika J., ***Gryguc G.*** *2011. Post-glacial vegetation and environment of the Labanoras region, East Lithuania: implications for regional history. Geological Quarterlay, 55(3), 269–284.*

Lithostratigraphy

Descriptions of the sediments are given in Table 3. The Lateglacial sediments consisted of silty/sandy gyttja and sand in mostly cases. The layers of gyttja and peat are predominated in the Holocene part of the stratum. In the Lateglacial the content of the organic matter is low but rises in the Holocene part of the sequencies analysed.

Table 3. Description of the sediments

Depth, cm	Sediment description
1	**2**
Lake Briaunis	
0-300	Peat, black
300-373	Peat, brownish with numerous remains of trees
373-718	Gyttja, brownish grey
718-800	Gyttja, Sandy clayey
Lake Verpstinis	
140-300	Peat, brown, poorly decomposed
300-500	Peat, dark brown, middle decomposed
500–571	Peat, dark brown, compact
571-600	Gyttja, light grey
Lavariškės Bog	
0–810	Peat, brownish black, poorly decomposed
810 – 892	Gyttja with peat, dark brownish
892 – 897	Gyttja, light grey
897 – 912	Peat, black, well decomposed
912 – 917	Gyttja, light brownish
917 – 928	Gyttja with peat, dark brown
928 – 944	Gyttja, silty, brownish
944 – 967	Gyttja, silty, brownish with light grey layers
967–1000	Gyttja, silty, grey, compact
Lake Pakampis	
60-119	Mud
119-307	Gyttja, light grey
307-370	Sand with admixture of gyttja
370–950	Gyttja, black, compact
Lake Pakastuva	
16-48	Peat, black
48-57	Peat, black-grey
57-100	Peat, brownish black
100-280	Peat, black-brown
280-300	Peat with plant remnants, greyish black
300-330	Gyttja with peat, black grey
330-360	Gyttja, greyish black
360-490	Gyttja, black grey with mollusca shells
490-595	Gyttja with detritus of mollusca shells, light grey
595-600	Peat, greyish black
600-627	Sand loam, brownish grey
627-631	Gravel, grey with sand
Zervynai outcrop	
40-47	Sand, redish brown
47-73	Gyttja, sandy, greenish brown with dark brown
73-83	Sand, light grey
83-155	Gyttja, sandy, black, compact
155-165	Sand, redish brown

1	2
Rudnia outcrop	
15-30	Sand, light brownish grey
30-50	Gyttja, sandy, black, compact
50-65	Gyttja, sandy, grey

Chronology

The results of the ^{14}C dating are summarised in Table 4. According to results obtained sedimentation in the Zervynos and Rudnia outcrop started during the Lateglacial, while in Briaunis, Verpstinis, Pakampis Pakastuva lakes and Lavariškės bog, accumulation of the sediment strata started in the Holocene.

Table 4. Results of ^{14}C dating

No.	Depth (cm)	^{14}C (yr BP)	Calibrated age (cal yr BP)	Laboratory code	Dated material
Briaunis Lake					
1	155–160	2760±50	2886–2786	Vs-2384	Total organic carbon
2	205–210	3235±65	3485–3385	Vs-2277	Total organic carbon
3	260–265	5100±60	5828–5750	Vs-2385	Total organic carbon
4	335–340	6040±120	7160–6730	Vs-1909	Total organic carbon
5	350–355	6090±120	7160–6800	Vs-1908	Total organic carbon
6	390–395	6510±220	7595–7235	Vs-2278	Total organic carbon
7	525–530	7920±40	8750–8740	Beta-351991	*Alnus* seed
8	770–780	8600±470	10250–8950	Vs-1914	Total organic carbon
Verpstinis Lake					
1	188–190	1905±120	1990–1705	Vs-2263	Total organic carbon
2	256–258	2935±90	3215–2960	Vs-2264	Total organic carbon
3	328–330	4335±90	5050–4825	Vs-2265	Total organic carbon
4	424–426	7315±90	8200–8015	Vs-2266	Total organic carbon
5	512–514	9240±310	10830–10135	Vs-2267	Total organic carbon
6	566–568	9555±120	11095–10720	Vs-2268	Total organic carbon
Lavariškės bog					
1	195–200	1800±60	1644–1808	Ki-12179	Total organic carbon
2	350–355	3460±70	3647–3825	Ki-12180	Total organic carbon

3	510–515	5930±80	6858–6665	Vs-2377	Total organic carbon
4	620–625	6580±235	7950–7560	Vs-2317	Total organic carbon
5	815–820	8310±125	9460–9195	Vs-2318	Total organic carbon
Pakampis Lake					
1	328–332	2930 ± 50	3010–3178	Poz-62616	*Alnus glutinosa* seed
2	504–508	4495 ± 35	5078–5260	Poz-62617	*Alnus glutinosa* seed
3	600–604	4660 ± 35	5344–5452	Poz-62615	*Alnus glutinosa* seed
4	688–692	7980 ± 60	8729–8956	Poz-62618	*Alnus glutinosa* seed
Pakastuva Lake					
1	159–160	4275±150	5098–4626	Vs-2156	Total organic carbon
2	292–296	4950±110	5847–5606	Vs-2158	Total organic carbon
3	395–396	5800±40	6653–6549	Poz-44797	Total organic carbon
4	496–497	7180±50	8041–7966	Poz-44799	Total organic carbon
5	598–599	7240±450	8570–7683	Vs-2077	Total organic carbon
Zervynai outcrop					
1	50–52	10500±290	12188–12585	Vs-2284	Total organic carbon
2	68–70	11610±60	13369–13536	Poz-58686	Total organic carbon
3	84–86	11670±70	13436–13564	Poz-51806	Total organic carbon
4	140–142	12290±70	14076–14392	Poz-51807	*Pinus* seed
5	148–150	12260±60	14057–14271	Poz-58687	Total organic carbon
Rudnia outcrop					
1	30–32	11520 ± 60	13300–13537	Poz-58639	Total organic carbon
2	42–44	11770 ± 50	13543–13780	Poz-58683	Total organic carbon
3	48–50	11770 ± 90	13730–13495	Vs-2287	Total organic carbon
4	60–62	11440 ± 50	13233–13480	Poz-58684	*Pinus* seed

Plant macrofossils survey

During plant macrofossil analysis, plant macrofossils of 50 taxa were found in sediments of Briaunis Lake, 39 – of Verpstinis Lake, 26 – of Lavariškės bog, 38– of

Pakampis Lake and 35 – of Pakastuva Lake. Sediments of Zervynai outcrop contained macroremains of 12 and these of Rudnia outcrop – 21 different taxa (Table 5).

Table 5. Local plant macrofossils zones (LMAZ) from the studied sediment sequences

LMAZ	Depth, cm	Description
Briaunis Lake		
B_{M-1}	575-800	Aquatic plants prevail in the zone. *Chara* sp. oospores are abundant in the lower part of the interval (780–800 cm) whereas in the upper part (575–780 cm) their amount considerably reduces; other species i.e. *Nymphaea alba*, *Najas marina*, *Ceratophyllum demersum*, and *Potamogeton natans* are dominant here. The littoral zone was overgrown with *Schoenoplectus lacustris* and the shores - with birch. Also *Picea* sp. fossils were identified
B_{M-2}	330-575	The composition of flora in the water basin remains almost the same as well as the dominant plant species. Only *N. alba* and *N. marina* are found in a greater abundance. *Myriophyllum verticillatum*, *Potamogeton perfoliatus* and small amount of *Lemna trisulca* appear. The number of wetland plants increases. *S. lacustris* and *Carex* sp. fossils are found in especially great abundance. Isolated *Cladium mariscus* fruits occur. This zone is rich in macrofossils of trees predominated by *Betula* sect. *Albae* and *Alnus glutinosa*.
B_{M-3}	200-330	Wetland plants i.e. *Scirpus sylvaticus, Carex* sp., *Ranunculus sceleratus* and *Menyanthes trifoliata* are dominant in this zone. Whereas *Urtica dioica* is most abundant among xeromezophytes. Menatime aquatic taxa is represented by *L. trisulca* seeds only. Small amount of alder and birch macrofossils recorded.
B_{M-4}	5-200	Water plants are absent and wetland plants predominate in this zone. Furthermore richness of the recorded species is higher. *Scirpus sylvaticus*, *R. sceleratus, M. trifoliata* and *Carex* sp. are found in a greatest abundance. Species of plants growing in dryer habitats i.e. *Rumex crispus*, *Hypericum perforatum*, *Fragaria vesca*, *U. dioica* occur in a greater number.
Verpstinis Lake		
V_{M-1}	570-600	In the lower part of the section, few macro-remains were registered. *Chara* sp. dominated among water plants The poor remains of tree macrofossils
V_{M-2}	425-570	This interval is abundant in the in macro-remains of plants typical for water and wetland habitats. The drop in *Chara* representation alongside with the expansion of *P. natans, P. colratus, P. pusilus, N. alba*, *Najas flexilis.* Wetland plants are predominanting and their species composition is rich. *Carex* sp., *Carex elata, Lycopus europaeus, Polygonum lapathipholium, Polygonum persicaria, M. trifoliata* and *Urtica* sp. are found in greatest abundance. *Pinus* sp, *Picea* sp. and *B. sect. Albae* predominated in the forest composition
V_{M-3}	306-425	Wetland plants are dominant, but their species composition is poorly. Meanwhile, *Carex* sp. are found in the greatest abundance. The number of water plants decrease and in the upper part of the section (starting at the

		depth 350 cm). Coniferous and *B. sect. Albae*. dominate in this zone.
V_{M-4}	237-306	No macrofossils of aquatic taxa were found. *Carex* sp. are still well represented. *M. trifoliate*, *Andromeda polifolia* and *Oxycoccus* sp. appear. The shore overgrown with birches and coniferous.
V_{M-5}	202-237	The number of wetland plants increases (*Andromeda polifolia*, *Oxycoccus* sp., *Rhynchospora alba)* in the zone. The *Carex* remains number almost the same.
V_{M-6}	142-202	The upper part of the poorly decomposed peat predominated by plant remains typical of wetland habitats. Trees are represented by spruce and birch.
Lavariškės bog		
L_{M-1}	950-1000	The variety of the recorded plant species is poor in this zone. No macrofossils of wetland taxa were found. The single speciments of *Chara* sp., *Potamogeton* sp., and *P. natans* represent group of the water plants. Only single finds of *B.* sect. *Albae* macroremains are presented when *Cristatella mucedo* statoblast are abundant.
L_{M-2}	860-950	The number of *Potamogeton* sp. and *P. natans* macroremains increases in this zone. Presence of scattered remains of *Andromeda polifolia*, *M. trifoliata*, *U. dioica, Vaccinium* sp. is coincident with the spread of *Carex* sp. in the spectra. A great number of *B.* sect. *Albae*, *Betula pubescens* accompanied by *Pinus* sp. suggests the local presence of these trees.
L_{M-3}	780-860	Number of identified *Potamogeton* species decreased among aquatic taxa while the presence of *Chara* sp. Oospores started to increase. Alongside wit the mentioned speciments, *N. alba* established in the basin. Species variety of the plant of shores and wetlands remains stable. Pine and birch predominate among trees.
L_{M-4}	650–780	Water plants are represented by the *N. alba* in this zone.while plants typical for the shores are better represeneted i.e. *Carex* sp., *C. riparia*, *Andromeda polifolia*, *M. trifoliata*, *Vaccinium* sp. flourishes in the area according the plant macrofossil data. Numebr of birch and pine decreased remarkably, and the single fruits of *Tilia* sp. were recorded.
L_{M-5}	500–650	Water plants are absent in this zone where taxa typical for the shores and wetlands predominated. Especillay great variety of *Carex* sp. recorded. Birch and lime flourished along the shores.
L_{M-6}	275–500	The number of bich macrofossils is great in this zone. Simultaneously various species of *Carex* sp. flourishes and the number of *Potentilla* sp. and *Cicuta virosa* increases. At the same time representation of *Andromeda polifolia* decreased.
L_{M-7}	90–275	The variety of the plant species typical for wetlands and shores decreased in this zone. *Carex* sp. predominates in the zone. Representation of *Andromeda polifolia*, *M. trifoliata* and *Potentilla* is high ion this zone as well. In the surroundings of the palaeoboasin birch and pine flourished according to plant macrofossil data.

L_{M-8}	0–90	*Andromeda polifolia* predominates among other taxa and single speciments of *Lycopus europaeus* and *Persicaria lapathifolia* were recorded alongside with the scattered finds of *Vaccinium* sp.
Pakampis Lake		
P_{M-1}	680–900	The richness of the flora is low in this zone. *N. alba* predominates among the water plants while *Typha latifolia* flourished along the shore. Recorded single finds of *U. dioica* and *Glyceria* sp. Representation of trees is negligible either i.e. scattered seeds of *A. glutinosa* and *B.* sect. *Albae* identified. Alongside with the mentioned tree species pine occurred.
P_{M-2}	500–680	*Chara* sp., *Najas marina* and *P. natans* alongside with the *N. alba* spread in the basin. While the representation of the taxa typical for wetland and shore communities stays negligeble in the spectra. Only *Carex* sp., *U. dioica*, and single finds of *Lychnis* sp. and *Rumex* sp. recorded. *A. glutinosa*, *B. pubescens* and *B.* sect. *Albae* predominate among trees. Scattered seeds of *Pinus* were identified.
P_{M-3}	300–500	Number of *N. alba* and *N. marina* is higher in this zone. Alongside with the mentioned taxa *Nuphar lutea* occured. Number of *U. dioica* iand *Carex* sp. Increased approaching the upper limit of the zone.
P_{M-4}	125–300	Number of *N. alba* and *N. marina* remarkably increased, at the same time macrofossils of *Nuphar lutea* were recorded. Meantime plants of the coastal zone are sparse in the spectra, number of *U. dioica* macrofossils decreased and *Carex* sp. predominates in the zone. Alongside wit the mentioned taxa macroremains of *S. lacustris*, *T. latifolia*, *R. sceleratus* and etc were recorded. *A. glutinosa* flourishes along the coast and birch with pine are common in area.
P_{M-5}	50–125	No macrofossils of aquatic taxa were found. Plants of wetlands and shores flourishes in this zone. A big number of of *Carex diandra*, *Lychnis* sp., *Juncus* sp. and *Glyceria* sp. were recorded.
Pakastuva Lake		
P_{M-1}	556–650	The zone is characterized by low number of plant macroremains. Pieces of *Pinus* epidermis are common and single fruits of *A. glutinosa* and *B.* sect. *Albae* occur as well as *N. alba* and *N. marina* representing group of water plants. *Carex* vesicaria and M. *trifoliata* represent vegetation of wetland. Some particles of charcoal were recorded in the middle of this zone
P_{M-2}	490–556	Variety of plant species is poor in this zone where finds of *N. alba* and *N. marina* are common. Shore vegetation is represented by the several remains of *T. latifolia* and *Carex* sp. Macrofossils of *B.* sect. *Albae* predominate among the trees. Macroremais of *Pinus* nearly dissapear in this zone
P_{M-3}	400–490	The number of identified plant macrofossils as well as variety of identified taxa is especially low in this zone. Only single finds of *Pinus* and *Betula* are detected in the group of trees. Sharp reduction of *Najas marina* and scattered finds of *N. alba* characterize vegetation of water basin in this zone. The shore vegetation, represented by *Typha* sp. and *Carex* sp. is sparse
P_{M-4}	298–400	The zone is dominated by aquatic plants such as *Nuphar lutea*, *Chara* sp., *P. natans* and *N. alba*, but *N. marina* makes a majority. Group of wetland and shore plants is represented by single *S. lacistris*, *Ranunculus* sp.,

		Typha sp. and *U. dioica* macroremains. The vicinities of palaeobasin was occupied by birch with admixture of alder and spruce according to plant macrofossil data.
$P_{M\text{-}5}$	218–298	Plants of wetland and shores predominate in this zone. Remains of different species of sedges (*Carex* sp., *C. echinata*, *C. pseudocyperus*, *C. distans*), *M. trifoliata, Lycopus europaeus* and *T. latifolia* represent this group. Water plants disappear. Significant rise of tree finds (alder and birch) is fixed in comparison with the previuos zone.
$P_{M\text{-}6}$	98–218	Plants of wetland and shores still dominate. Finds of *U. dioica* are especially numerous. Amount of birch and alder drop on the top of this zone. The seed of pine was found at the depth of 112-124 cm
$P_{M\text{-}7}$	62–98	Variety of wetland plants (*Carex* sp., *C. vesicaria*, *C.echinata*, *C.nigra*, *C. lepidocarpa, Polygonum hidropiper*, *P. lapatifolium* et al.) show overgrowth of terrain. Birch dominated in the vicinities of palaeobasin.
$P_{M\text{-}8}$	18–62	Sudden spread of water plants (*Chara* sp., *Potamogeton* sp., *P. pusillus*, *P. praelongus*) poin to regeneration of the water basin.
Zervynai outcrop		
$Z_{M\text{-}1}$	149-164	Variety of discovered plant species is poor in this zone. Remains of shore plants *T. latifolia* and *M. trifoliata* predominate in this zone. Single fruits of *Chara* and *Potamogeton* occured as well.
$Z_{M\text{-}2}$	100-149	*Chara* sp. dominated among water plants. Herbs of wetland were represented by *Carex* and *M. trifoliata*. *Pinus* and *Betula* forest prevailed in the territory. Herbs were common as well
$Z_{M\text{-}3}$	48–100	The zone is characterized by cold water species *P. filiformis* and *Chara* sp., which dominated the palaeobasin. The littoral zone was overgrown by sedges and cold-tolerant *Selaginella selaginoides.* The single finds of *B.* sect. *Albae* macroremains are presented.
Rudnia outcrop		
$R_{M\text{-}1}$	50–65	Plants of wetlands and shores predominate this zone. Remains of different species of sedges i.e. *Carex* sp., *C. vesicaria*, *C. lasiocarp*a, alongside with the *M. trifoliata, Cirsium palustre, S. lacustris* and *Potentilla* sp. represent this group. In the water basin plants of *Potamogeton* genus, including *P. natans*, *P. praelgonus,* together with *Hippuris vulgaris* and *Chara* sp. flourished. The megaspores of *S. selaginoides* were found at the depth of 65 cm. The vicinities of palaeobasin were occupied by birch, pine, spruce.
$R_{M\text{-}2}$	41–50	The number of wetland plants, especially sedges, decreased and *M. trifoliata* predominate in this zone. A single find of *Potamogeton sp.* represents water plants in this zone. Hovewer, *T. latifolia* and *U. dioica* appear. Meantime, other macrofossils are represented sporadically or recorded as individual finds. Composition of the tree species is rather stable.
$R_{M\text{-}3}$	25–41	Scattered finds of *T. latifolia*, *S. lacustris*, *M. trifoliata, Carex vesicaria, Potentilla* sp. and *Carex* sp. represent the shore vegetation in this zone. Simultaneously *Cristatella mucedo* statoblast are common in spetra. Birch strongly predominates among tree's while pine is recorded sporadically.
$R_{M\text{-}4}$	15–25	Scattered finds of the plant macrofosills were recorded in this zone.

7. DISCUSSION

7.1. Complexes of plant palaeocommunities

To sum up the information provided in this chapter:

a) The defined vegetation communities and amount of plants did not vary much in palaeobasins and their surroundings during the Lateglacial because of unfavorable climate conditions. The *Charetea fragilis* community dominated the palaeobasins with limited amount of nutrient elements. Minor *Potamogetonetea pectinati* communities were also present. The number of communities had increased during the warmer intervals of the Lateglacial, e.g. the GI-1(c-a) climatic event. After soils had stabilized and environmental conditions improved, the *Phragmito*-*Magnocaricetea*, *Scheuchzerio–Caricetea nigrae*, *Artemisietea vulgaris* and *Molinio–Arrhenatheretea* communities started to colonize the shores of the palaeobasins (Table 6).

b) In Holocene, an increase in number of vegetation communities and characteristic plants was fixed, likely because of noticeable changes of environmental conditions. The *Potamogetonetea pectinati* and *Charetea fragilis* communities dominated the early Pleistocene basins, while their shores were populated with the *Phragmito*-*Magnocaricetea*, *Scheuchzerio–Caricetea nigrae*, *Artemisietea vulgaris*, and *Molinio-Arrhenatheretea* communities. In the surroundings of the palaeobasins the *Alnetea glutinosae*, *Oxycocco-Sphagnetea* and *Bidentetea tripartitae* communities were established. Communities of water plants (e.g. *Charetea fragilis, Potamogetonetea pectinati*) started to disappear in the middle Holocene because of wetland formation and basin overgrowing. That is why the *Lemnetea minoris* community which favors shallow waters thrived. In the late Holocene, the *Nardetea strictae* and *Epilobietea angustifolii* communities started to appear among the already established species (Table 7).

Table 6. Lateglacial plant palaeocommunities

Phytosociology class	Zervynos outcrop	Rudnia outcrop	Lavariškės bog
GI-1e climatic event			
Charetea fragilis	X	-	-
Potamogetonetea pectinati	X	-	-
Phragmito-Magnocaricetea	X	-	-
Scheuchzerio-Caricetea nigrae	X	-	-
GI-1d climatic event			
Charetea fragilis	X	-	-
Potamogetonetea pectinati	-	-	-
GI-1(c-a) climatic event			
Charetea fragilis	X	X	-
Potamogetonetea pectinati	X	X	-
Phragmito-Magnocaricetea	-	X	-
Scheuchzerio-Caricetea nigrae	X	X	-
Artemisietea vulgaris	-	X	-
Molinio-Arrhenatheretea	-	X	-
GS-1 climatic event			
Charetea fragilis	X	-	X
Potamogetonetea pectinati	-	-	X

Table 7. Holocene plant palaeocommunities

EARLY HOLOCENE					
Phytosociology class	**Lavariškės bog**	**Verpstinis Lake**	**Briaunis Lake**	**Pakampis Lake**	**Pakastuva Lake**
	1	**2**	**3**	**4**	**5**
Charetea fragilis	X	X	X	-	X
Potamogetonetea pectinati	X	X	X	X	X
Phragmito-Magnocaricetea	X	X	X	X	X
Scheuchzerio-Caricetea nigrae	X	X	X	-	X
Oxycocco-Sphagnetea	X	X	-	-	-
Artemisietea vulgaris	X	X	X	-	-
Bidentetea tripartitae	-	X	-	-	-
Alnetea glutinosae	-	-	X	X	-
Molinio-Arrhenatheretea	-	-	X	-	-
MIDDLE HOLOCENE					
Charetea fragilis	-	-	-	X	X
Potamogetonetea pectinati	-	X	-	X	X
Lemnetea minoris	-	-	X	-	-

Phytosociology class	1	2	3	4	5
Phragmito-Magnocaricetea	X	X	X	-	X
Scheuchzerio-Caricetea nigrae	X	X	X	X	X
Oxycocco-Sphagnetea	X	X	-	-	-
Artemisietea vulgaris	X	-	X	X	X
Bidentetea tripartitae	-	X	X	X	-
Alnetea glutinosae	-	-	X	X	X
Molinio-Arrhenatheretea	-	-	X	-	-
LATE HOLOCENE					
Charetea fragilis	-	-	-	X	X
Potamogetonetea pectinati	-	-	-	X	X
Phragmito-Magnocaricetea	X	X	X	X	X
Scheuchzerio-Caricetea nigrae	X	-	X	X	X
Oxycocco-Sphagnetea	X	X	-	-	-
Artemisietea vulgaris	X	X	X	-	X

Phytosociology class	**1**	**2**	**3**	**4**	**5**
Bidentetea tripartitae	X	-	X		X
Alnetea glutinosae	-	-	X	X	X
Molinio-Arrhenatheretea	-	-	X	X	-
Nardetea strictae	-	-	X	-	
Epilobietea angustifolii	-	-	X	-	X

7.2. Local vegetation variations and palaeoecological conditions in the studied palaeobasins

From the results presented in this chapter can be implied that the light loving and middle-light plants dominated the Lateglacial basins. The species transitional between cool and fairly warm habitats were predominating. The palaeo-basins were filled up with acidic to neutral water. The substrate had the nitrogen content varying from low to medium (Table 8). The shores were populated with plants, which were light loving to middle-light, and favored the transitional between fairly warm to warm habitats. They dwelled in the dampness and wet, from medium acidic to alkaline habitats, from low-nitrogen to nitrogen-rich soils. The cold-habitat vegetation appeared during the short-lived GI-1b climatic event (Table 9).

The Holocene basins were transitional between semi-shaded and middle light, fairly warm to warm. Their water was neutral to alkaline, the soils from low-nitrogen to nitrogen-rich (Table 10). The onshore conditions were transitional from middle-light to light loving and from fairly warm to warm. The soils were dampness and wet, from acidic to neutral reaction, and from low-nitrogen to very nitrogen-rich (Table 11).

Table 8 Lateglacial palaeoecological conditions in the investigated basins

Indicators of ecological conditions	**GI-1(c-a) climatic event**		
	Zervynai outcrop	**Rudnia outcrop**	**Lavariškės bog**
Light	Light loving plants	Middle-light plants	-
Temperature	Between indicators of cool conditions and indicators of fairly warm conditions	Indicators of fairly warm conditions	-
pH reaction	Between indicators of acidity and indicators of moderate acid soils	Indicators of neutral reaction	-
Soil nitrogen	Indicators of low nitrogen availability	Between indicators of low nitrogen and indicators of medium nitrogen soils	-

GS-1 climatic event			
Light	-	-	Between semi-shade plants and middle-light plants
Temperature	-	-	Indicators of fairly warm conditions
pH reaction	-	-	Indicators of neutral
Soil nitrogen	-	-	Indicator of medium nitrogen soils

Table 9. Lateglacial palaeoecological conditions of the paleobasines onshore

Indicators of ecological conditions	**GI-1e climatic event**		
	Zervynai outcrop	**Rudnia outcrop**	**Lavariškės bog**
1	**2**	**3**	**4**
GI-1e climatic event			
Light	Light loving plants	-	-
Temperature	Between indicator of fairly warm condition and indicator of warmth condition	-	-
Soil moisture	Indicators of very wet sites	-	-
pH reaction	Between indicators of neutral and indicators of alkaline reaction	-	-
Soil nitrogen	Between indicators of medium nitrogen and nitrogen-rich soils	-	-
GI-1(c-a) climatic event			
Light	Light loving plants	Middle light plants	-
Temperature	Indicators of cool conditions (GI-1b)	Indicators of fairly warm conditions	-

Soil moisture	Between indicators of dampness and indicators of wet soils	Indicators of wet soils	-
pH reaction	Between indicators of medium acidic (GI-1b) and indicators of neutral-alkaline reaction	Between indicators of medium acidic and indicators of neutral-reaction	-
Soil nitrogen	Indicators of low nitrogen	Indicators of medium nitrogen soils	-
GS-1 climatic events			
Light	-	-	Middle-light plants
Temperature	-	-	-
Soil moisture	-	-	Dampness indicators
pH reaction	-	-	Indicators of medium acidic reaction
Soil nitrogen	-	-	Between indicators of medium nitrogen and nitrogen-rich soils

Table 10 Holocene palaeoecological conditions of the paleobasines

Early Holocene					
Indicators of ecological conditions	**Lavariškės bog**	**Briaunis Lake**	**Verpstinis Lake**	**Pakampis Lake**	**Pakastuva Lake**
Light	Middle-light plants	Middle-light plants	Middle-light plants	Light loving plants	-
Temperature	Between indicators of fairly warm conditions and indicators of warmths condition	Between indicators of fairly warm conditions and indicators of warmth conditions	Between indicators of fairly warm conditions and indicatosr of warmth conditions	Between indicators of fairly warm conditions and indicators of warmth conditions	-
pH reaction	Indicators of neutral reaction	Between indicators of neutral and indicators of alkaline reaction	Indicators of neutral reaction	Indicators of neutral reaction	-
Soil nitrogen	Indicators of medium nitrogen soils	Between indicators of medium nitrogen and nitrogen-rich soils	Between indicators of medium nitrogen and nitrogen-rich soils	Indicators of medium nitrogen soils	-
MIDDLE HOLOCENE					
Indicators of ecological conditions	**Lavariškės bog**	**Briaunis Lake**	**Verpstinis Lake**	**Pakampis Lake**	**Pakastuva Lake**
Light	-	Between semi-shade plants and middle light plants	Between semi-shade plants and middle-light plants	Middle-light plants	Middle-light plants
Temperature	-	Between indicators of fairly warm	Between indicators of fairly warm conditions	Between indicators of fairly warm	Between indicators of fairly warm conditions and

		conditions and indicator of warmth conditions	and indicators of warmth conditions	conditions and indicators of warmth conditions	indicators of warmth conditions
pH reaction	-	Indicators of neutral reaction	Between indicators of neutral and indicators of alkaline reaction	Between indicators of neutral and indicators of alkaline reaction	Between indicators of neutral and indicators of alkaline reaction
Soil nitrogen	-	Between indicators of medium nitrogen and nitrogen-rich soils	Indicators of medium nitrogen soils	Between indicators of medium nitrogen and nitrogen-rich soils	Between indicators of medium nitrogen and nitrogen-rich soils
LATE HOLOCENE					
Indicators of ecological conditions	**Lavariškės bog**	**Briaunis Lake**	**Verpstinis Lake**	**Pakampis Lake**	**Pakastuva Lake**
Light	-	-	-	Middle-light plants	Middle-light plants
Temperature	-	-	-	Between indicators of fairly warm conditions and indicators of warmth conditions	Indicators of fairly warm conditions
pH reaction	-	-	-	Between indicators of neutral and indicators of alkaline reaction	Indicators of neutral reaction
Soil nitrogen	-	-	-	Between indicators of medium nitrogen and nitrogen-rich soils	Between indicators of low nitrogen and indicators of medium nitrogen soils

Table 11. Holocene palaeoecological conditions of the paleobasines onshore

EARLY HOLOCENE					
Indicators of ecological conditions	**Lavariškės bog**	**Briaunis Lake**	**Verptinis Lake**	**Pakampis Lake**	**Pakastuva Lake**
1	**2**	**3**	**4**	**5**	**6**
Light	Light loving plants	Middle-light plants	Middle-light plants	Middle-light plants	-
Temperature	Indicators of fairly warm conditions	Indicators of fairly warm conditions	Between indicators of fairly warm conditions and indicators of warmth conditions	Indicators of fairly warm conditions	-
Soil moisture	Indicators of wet soils	Indicators of wet soils	Indicators of wet soils	Between indicators of dampness and indicators of wet soils	-
pH reaction	Between indicators of acidic and indicators of medium acidic reaction	Indicators of neutral reaction	Between indicators of medium acidic and indicators of neutral-reaction	Indicators of neutral reaction	-
Soil nitrogen	Indicators of low nitrogen soils	Between indicators of medium nitrogen and nitrogen-rich soils	Indicators of medium nitrogen soils	Very nitrogen-rich soils	-
MIDDLE HOLOCENE					
Light	Light loving plants	Light loving plants	Light loving plants	Middle-light plants	Middle-light plants
Temperature	Between indicators of fairly warm conditions and indicators of warmth conditions	Between indicators of fairly warm conditions and indicators of warmth conditions i	Indicators of fairly warm conditions	Indicators of fairly warm conditions	Indicators of fairly warm conditions

Soil moisture	Between indicators of dampness and indicators of wet soils	Between indicators of dampness and indicators of wet soils	Indicators of wet soils	Between indicators of dampness and indicators of wet soils	Between indicators of dampness and indicators of wet soils
pH reaction	Indicators of medium acidic reaction	Between indicators of medium acidic and indicators of neutral-reaction	Indicators of medium acidic reaction	Between indicators of medium acidic and indicators of neutral-reaction	Between indicators of medium acidic and indicators of neutral- reaction
Soil nitrogen	Between indicators of low nitrogen and indicators of medium nitrogen soils	Between indicators of medium nitrogen and nitrogen-rich soils	Indicators of medium nitrogen soils	Between indicators of medium nitrogen and nitrogen-rich soils	Between indicators of medium nitrogen and nitrogen-rich soils
LATE HOLOCENE					
Light	Light loving plants	Middle-light plants	Light loving plants	Middle-light plants	Middle-light plants
Temperature	Between indicators of fairly warm conditions and indicator of warmth conditions	Between indicators of fairly warm conditions and indicators of warmth conditions	Indicators of fairly warm conditions	Between indicators of fairly warm conditions and indicators of warmth conditions	Indicators of fairly warm conditions
Soil moisture	Between indicators of dampness and indicators of wet soils	Indicators of dampness soils	Between indicators of dampness and indicators of wet soils	Between indicators of dampness and indicators of wet soils	Indicators of very wet soils
pH reaction	Indicators of medium acidic reaction	Indicators of medium acidic reaction	Between indicators of acidic and indicators of medium acidic	Between indicators of medium acidic and indicators of neutral-reaction	Indicators of medium acidic reaction
Soil nitrogen	Between indicators of low nitrogen and indicators of medium nitrogen soils	Indicators of medium nitrogen soils	Between indicators of low nitrogen and indicators of medium nitrogen soils	Between indicators of medium nitrogen and nitrogen-rich soils	Indicators of medium nitrogen soils

7.3. Evolution of the Lateglacial and Holocene environments

A new data on the vegetation variety and its history as well as basin evolution during the Lateglacial and Holocene was obtained from the integrated sediment investigations in this study. The processes depended on climate changes and interaction between different communities. After the Lastglacial, the Lithuanian area gradually recovered from ice sheets that have retreated because of climate warming. However, the process was gradual because of several cooling events that affected the studied environments. These climatic events were of global character. The earliest post-glacial events defined in the palaeobasin sediments of Lithuania were correlated with the GI-1e climatic event (Lowe et al., 2008).

GI-1e climatic event (~14650-14050 cal yr BP)

Sediments assigned to the GI-1e climatic event were found in the Zervynos outcrop. It seems that numerous findings of pine pollen in those sediments had to point out that pine tries predominated among the vegetation. According to Huntley and Birks (1983) if values of pine pollen are greater than 50%, pine pollen could have originated from a local source. However, no pine macrofossils which would have confirmed the local pine tree presence were detected in the sediments. Pine macrofossils of similar age were discovered in southeastern Lithuania (Stančikaitė irk t., 2008). The latter fact is confirmed by Veski's et al. (2014) reconstructions of climatic conditions in southern Latvia. The results show that climate was very cold at that time: the average temperature of summers ranged from 8°C to 12°C, while in winters it dropped down -23°C and -20°C (Veski et al., 2014). Variations of the oxygen isotope ($\delta^{18}O$) curve for the studied sediments of that time might be explained by the increase in evaporations, which, in turn, might have been caused by the increasing annual temperature. On the other hand, the carbon isotope ($\delta^{13}C$) curve points toward dry climate at that time. The average July temperature could have reached 13.5 °C (Kolstrup, 1980), what was confirmed by the presence of *Typha latifolia* macrofossils in the sediments. The climate was warming in the whole North Atlantic region (Björk et al., 1998). Soil cover was unstable at the beginning and comprised only few grass species. Soils have stabilised later, as was implied from the increasing amounts of organic matter and carbonates in the sediments under consideration.

The water level in the palaeobasins was high leading to the accumulation of terrigenic sediments (sand). The stonewort (*Charetea fragilis*) communities dominated those waters with insufficient nutrients, while even pondweeds (*Potamogeton* sp.) were found among stonewort communities in the Zervynos sediments. Their habitats have had low or medium contents of biogenic matter (nitrogen) and transitional from medium acidic to almost neutral water (pH 6 –7).

GI-1d climatic event (~14050-13900 cal yr BP)

An average annual temperature decreased during the GI-1d climatic event. The results have shown that the summer and winter temperature averages in the eastern Baltic region dropped by 2°C (Veski et al., 2014) compared to the previous averages. The carried out isotopic investigations pointed out to similar climatic conditions. The obtained oxygen isotope ($\delta^{18}O$) curve reached negative values, what might be explained by climate cooling. Soil cover was unstable, what was confirmed by the decreased amount of organics and carbonates. The vegetation had reacted to those climate changes, i.e. a number of herbaceous plants, especially the *Artemisia*, Cyperaceae and Poaceae, increased. Numbers of pine trees decreased, while those of birch trees increased, also indicating the deterioration of the climatic regime. Sparse findings of pine epidermis in the studied sediments might be explained by the pine tree distribution near the local water basins. Pine macrofossils were discovered in southern Lithuania by the previous investigations (Stančikaitė et al., 2008). The palaeobasin water level has remained high, water was nutrient-poor and translucent.

GI-1(c-a) climatic event (~13900-12850 cal yr BP)

The most prominent warming in the Lateglacial was recorded by the sediments that had formed during the GI-1c climatic event. An average summer temperature reached 12°C, while a winter average temperature was in a range of -12°C and -15°C (Veski et al., 2014). A stable soil cover had formed as was indicated by the increased amount of organics in the studied sediments. The conditions became favorable for the vegetation expansion. Pine trees expanded fast and occupied southeastern Lithuania. The great number of pine material in the studied sediments indicates not only climate warming but also specific geology of the region. Sandy soils of the sandur plane dominating the area highly suited for the pine tree growth. The studied voluminous *Pinus* sp. macrofossils confirmed that they were present in the palaeobasin surroundings of that time. Pine macrofossils of that time were abundant also in Poland and Estonia (Ralska-Jasiewiczowa, 2004; Amon et al., 2014). The presence of *Pinus* sp. in the studied sediments is a good indicator that an average July temperature might have exceeded +12°C (Kultti et al., 2006). That is in a good agreement with an average July temperature of 13–20°C reconstructed for Western and Central Europe (Peyron et al., 2005; Heiri et al., 2007) and for the eastern Baltic-Belarusian region (Veski et al., 2014). Tree-birch grew along with pine in the palaeobasin surroundings. The local presence of birches has been confirmed by the results of plant macrofossil investigations. *Betula* sect. *Albae* macrofossils of that time have been detected also in the east Baltic region (Veski et al., 2012; Amon et al., 2014). On the other hand, the amount of birch pollen is relatively low, ranging from 5.2 to 17.2%, in the pollen record. According to Huntley and Birks (1983), values of birch pollen greater than 10% would have indicated a local distribution of those trees. In the vicinity of the Rudnia palaeobasin a spruce was found among pine and birch trees. Dump soils are needed for the spruce growth; therefore the spruce presence can be an indicator of wet climate at that time. Spruce macrofossils of similar age were discovered in NW Lithuania (Stančikaitė et al., 1998). During the GI-1c climatic event, *Artemisia* as well as plants of Cyperaceae, Poaceae and Chenopodiaceae families grew in the area. The detected decrease in terrigenic matter and increase in organic and $CaCO_3$ likely indicate a growing amount of biomass. The earliest indicators of basin eutrophication appeared at that time and a part of basins entered mesotrophic stage of their development. The water level in those basins was low, reaching only 2 m as was implied from the fact that macrophites had appeared in the basins. The earlier diatomic algae investigations in the SE Lithuania (Kabailienė, 2006) have supported the shallow basin version. Improvement of the climatic conditions (growth of temperature and suitable humidity) were reflected in the plant macrofossil records as well. The palaeobasins were populated with communities of (*Potamogetonetea pectinati*) when water level had dropped and water quality had changed. Even though the climate had warmed the water of palaeobasins remained medium-warm, as was indicated by endocarps of *Potamogeton filiformis* (Matuszkiewicz, 2001, Velichkevich and Zastawniak, 2006) in the sediments. Statoblasts of *Cristatella mucedo* highly sensitive to temperature drops (Okland and Okland, 2010) were discovered in the sediments. The latter fact confirmed the stability of environmental conditions in the palaeobasins at that time. The palaeobasin margins were populated by plants of heliophilous, transitional from medium-warm to warm habitats. Plants grew on wet, poorly-aerated and transitional from dump to wet soils. Plants of dryer habitats were also present in the closest proximity as indicated by a nitrophylic species of *U. dioica* found in the Rudnia sediments. The Rudnia and Zervynos palaeobasins might have started to over-grow and turn into wetlands at that time. The marshy shores were populated with plants belonging to communities of *Phragmito-Magnocaricetea*. The peaty shores of water basins have been occupied by *Scheuchzerio-Caricetea nigrae* communities.

Vegetation changes during the later GI-1b climatic event were revealed in the Zervynos pollen and plant macrofossil diagrams. An increase in number of herbaceous plants (*Artemisia*, Poaceae, Cyperaceae, *Chenopodium*) and decreased amounts of pine trees are indicators of an open landscape. Junipers (*Juniperus*) thrived in the well-illuminated and dry habitats. These vegetation changes might be related to the Gerzensee oscillation well pronounced in the large part of Europe and characterized by a short-lived climate cooling (Lotter ir kt., 1992; Björck ir kt., 1998). The climate cooling is also indicated by findings of *P. filiformis* endocarps and *Selaginella selaginoides* megaspores in the studied sediments. The amount of the terrigenous matter has increased, while that of organic and $CaCO_3$ have decreased in the Zervynos outcrop at the time of the consideration. The latter fact might be explained by the ongoing erosion, soil destruction and decreasing productivity of water basins. The increased number of carbonates and decreased number of organic matter in the Rudnia palaeobasin of that time may evidence a decrease in vegetation. This is confirmed also by the plant macrofossil data. These changes might have been related to a short-lived cooling episode. However this climatic event cannot be properly reconstructed without results of a pollen analysis. Similar indications of that event were described in the neighboring areas (Amon et al., 2011).

During the GI-1a climatic event, the climate has warmed again, however these changes were less prominent in comparision with GI-1a interval. Stable soils were formed as was indicated by the increased organic and $CaCO_3$ content in both investigated sequences. Later, aeolian processes started in the Rudnia area leading to the considerable increase in terrigenic matter. It seems that is why a number of plants decreased, moreover some plants fully disappeared. The sedimentation stopped in the Rudnia basin at that time. The above mentioned aeolian processes might have been a case.

GS-1 climatic event (~12850-11650 cal yr BP)

The vegetation has changed considerably during the GS-1 climatic event because of climatic changes. An overall drop of the average temperature in the region was fixed (Veski et al., 2014). The latter affected the whole ecosystem very much. The climate changed to aridic, what was implied from the increased values of carbon isotopes ($\delta^{13}C$). The thin forests in eastern and southeastern Lithuania were replaced by herbaceous plants, bushes and shrubs. Wormwoods (mugworts), wormseeds, sedges and meadow-grasses populated the opened spaces. Osiers occupied shores of the water basins, junipers thrived in the dryer habitats. Dwarf birches (*B. nana*) grew in the vicinity of the Lavariškės palaeobasin. The *B. nana* is a good climate indicator and its presence in the sediments might be related to cold periods of the Lateglacial (Lang, 1994). Abundances of this plant in the studied sediments mean that the climate was quite severe at that time. The latter fact is also supported by the findings of *S. selaginoides* (Snarskis, 1954) that tolerates low temperatures, is typical for tundra environments (Tobolski, 2006) and is absent in the modern Lithuanian flora. At the same time, the sediments predominating *Cristatella mucedo* plants might indicate that the water was not so cold in the Lavariškės palaeobasin because this species avoids water basins with temperatures lower than 11–16°C (Okland and Okland, 2000). Obviously the water temperature was higher than 11°C. This species usually dwells in shallow water basins (up to 2 m), which have medium or high calcium and medium magnesium contents, and semi-acidic waters (Okland and Okland, 2000).

Pine trees degraded, and the area was populated with birch trees mainly. This time in northern Europe is considered to be the coldest time after the degradation of the last ice sheet (Walker, 1995). At the same time c. 12500 cal yr BP a spruce (*Picea*) appeared in the area (Zervynos outcrop). Pollen content varying between 1–3 % might indicate that the species was local (Giesecke and Bennett, 2004; Latałowa and van der Knaap, 2006) and that fact was described during the earlier investigations (Stančikaitė et al., 2004, 2008, 2009; Heikkilä et al., 2009; Koff and Terasmaa, 2011, Zernitskaya et al., 2014). Meanwhile, macro remains of this tree discovered in western Lithuania (Stančikaitė et al., 2008), Estonia (Amon et al., 2014), Latvia (Heikkila et al., 2009) and Russia (Valiranta, 2005).

The *Picea* presence in the studied sediments shows that the region was quite humid at that time (Giesecke and Bennet, 2004). The sedimentation type in the Zervynos basin has also changed because of climate cooling, when contents of terrigenic matter have increased while those of organic matter have decreased. Similar Lateglacial environmental conditions were reported during the former investigations (Šinkūnas et al., 2005). The Lavariškės palaeobasin was quite shallow at that time, not exceeding 2 m. The findings of *Cristatella mucedo* statoblasts and *P. filiformis* endocarps in the sediments can support the previous statement. The latter species which is highly tolerant to cold usually dwells in quite dreggy waters (Väliranta, 2006). At the same time, the water level had risen in the Zervynos palaeobasin, what is recorded by dominating *Chara* sp. Algae that indicates quite low productivity of the basin also. Simultaneous rise of the water level was reported from the neighboring Poland (Starkel et al., 1998; Gałka et al., 2014) and other basins in Lithuania (Kabailienė, 2006). The rise of water level was related to the decrease in evaporation (Bohncke, 1993). Signs of the climatic warming can be observed in the pollen diagrams representing the late stages of the climatic event. At that time abundances of *Juniperus*, *Artemisia* and *Helianthemum* pollen have decreased. The latter species is an indicator of cool climate. At that time, the sedimentation of organic matter stopped in the Zervynos palaeobasin because of incipient aeolian processes that took place in the region (Molodkov and Bitinas 2006)

Early Holocene (11 650 – 8200 cal yr BP)

Global climate changes caused a gradual increase in average temperature after the 11500 cal yr BP (Björck et al., 1996). The process affected the whole northern hemisphere including Europe. It started from the shores of the Atlantic Ocean and continued inward the continent (Wohlfarth et al., 2002; Subetto et al., 2002). In the early Holocene, the average summer temperature was c. 13.3°C, while the average winter temperature was c. -9.6°C in northern Lithuania (Veski et al., 2014). An average winter temperature similar to the modern one was attained in the southern Baltic region c. 10 cal kyr BP, while an average summer temperature similar to nowadays one was attained later, c. 9 cal kyr BP (Veski et al., 2014). First signs of the climatic warming appeared in the sediments of 11100 cal yr BP in Lithuania (Stančikaitė et al., 2008, 2009). Such conditions were favorable for a forest-tundra development. According to the studied sediments, tundra plants disappeared with the warming climate giving a rise to the growth of trees. High contents of *Betula* pollen and *Betula* sect. *Albae* fruits in the sediments of that time evidence their dwelling in open places. Birches usually quickly populate open, none-forested places providing the conditions favorable for the growth of other trees (Kabailienė, 1990). A considerable amount of *Pinus* pollen along with those of birches was found in the studied sediments. Pine seedlings are not so sensitive to temperature changes; therefore those trees can populate open, none-forested places even in changeable climatic conditions. However, the growth of pine is slower than of birch, moreover that the seedlings are overgrown by a high grass. That is a reason why birches had populated the open places earlier than pines. The latter fact was prominent in the whole studied sections of that time. Open birch forests had dominated the early Holocene also in the other European countries (Bos et al., 2007; Mortensen et al., 2011). In those regions of SE Lithuania where sandy soils featured in large areas, the pine trees dwelled at that time (Kabailienė, 2006), while semi-simultiniously a spruce appeared in eastern Lithuania (Verpstinis). Its appearance in this region is dated back to c. 11500 cal yr BP (Gaidamavičius et al., 2011). The findings of earlier spruce macrofossils dated at 10800 cal yr BP indicate their only local presence in the study area. Such the early spruce appearance was fixed in NE Lithuania (Stančikaitė et al., 2008, 2009). *Ulmus* started to appear in the still thin birch-pine forests in the SE Lithuania. In the time period under consideration, c. 10300 cal yr BP, the elms were discovered also in northern Lithuania (Stančikaitė et al., 2014). Those trees populated the neighboring countries almost at the same time (Heikkilä et al, 2009; Kupryjanowicz, 2007; Niinemets and Saarse, 2009). This species is highly sensitive to droughts and requires a dump, fertail soil (Grime et al., 1988), therefore its population is a good indicator of habitats with such ecological conditions. The abundant findings of herbaceous plants in the studied sediments confirm the existence of open places. Families of Cyperaceae and Poaceae covered the lake shores and formed grasslands elswhere. Wormwoods featured the eroded soils. All this palaeoflora of the studied palaeobasins indicates that the thin, well-illuminated forests and grasslands had dominated the area.

At the beginning of the study period, shallow, down to 3 m, palaeobasins have been formed in the territory. A low water level was also characteristic for northeastern Poland (Ralska-Jasiewiczowa and Latalowa, 1996; Gałka et al., 2014b), Germany (Mortensen et al., 2011), and the Netherlands (Bos et al., 2007) at that time. However, a water level remained high in the Briaunis and Verpstinis palaeobasins. An elevated water level at that time was also observed in northern Lithuania (Stančikaite et al., 2014). High abundances of *Chara* sp. oospores which can grow down to 10 m (Hannon and Gaillard, 1997) support the fact of elevated water level. A great number of planktonic diatoms in the sediments of Briaunis Lake confirm its high water level (Gryguc et al., 2013). In the beginning, those palaeobasins were transparent, oligotrophic, carbonate-rich, and none-productive as was implied from the appearance of this pioneering species. The fact that the water basin was oligotrophic and nutrient-low can also be supported by the presence of *Cyclotella radiosa* and *Cyclotella ocellata* diatom species (Gryguc et al., 2013). A low productivity and very poor vegetation was also characteristic for the other studied palaeobasins when the sedimentation just started. The amount of *Chara* algae decreased, while the variety of water plants and their remains (*Potamogeton natans*, *Nymphaea alba* etc) increased c. 10800 cal yr BP, when the eutrophication process in the Verpstins water basin had intensified. A water level has dropped at that time. At the similar time, c. 10500 cal yr BP, a low water level was also fixed for Linówek Lake in northeastern Poland (Gałka et al., 2014a). The findings of *T. latifolia* and *Carex pseudocyperus* macrofossils in the early Holocene sediments of Verpstinis Lake are in a good agreement with the climatic amelioration (Gałka and Sznel, 2013). Semi-simultaneously, *T. latifolia* populates the Pakampis palaeobasin. This species can thrive only when the average July temperature is c. 13–16°C (Kolstrup, 1980). Commonly *C. pseudocyperus* thrives when the average July temperature is c. 13°C (Brinkkemper et al., 1987). The water temperature in the Verpstinis and Lavariškes palaeobasins might have been in a range of 11–16°C (Okland and Okland, 2000), what is indicated by a high amount of *Cristatella* *mucedo* statoblasts in the sediments. The presence of these plants in the studied sediments is good evidence that the climate was warm at that time.

At c. 10200 cal yr BP the environmental conditions and vegetation have changed drastically. The changes were mostly caused by the climate changes. The warming climate forced the already growing forests to change and differentiate gradually. Pine trees occupy the well-illuminated, thin forests, while a number of birch pollen decreases. Elm trees (*Ulmus*) appear in eastern Lithuania c. 10000 cal yr BP (Gaidamavičius et al., 2011) while in the central part of the country this taxa established at c. 9600 cal yr BP only. These trees pre-occupied the area by the end of the period, i.e. c. 8400 cal yr BP. Other deciduous trees such as *Corylus* and *Tilia* which had survived the Lateglacial maximum in central and south Europe (Bennett et al., 1991; Huntley and Prentice, 1993) started to appear and populate the fertile habitats at that time. In the beginning of the study period, c. 10200–10000 cal yr BP, nut-trees (*Corylus*) started to populate the eastern Lithuania (Gaidamavičius et al, 2011). However they did not show up in the particular areas of the eastern Lithuania until 9600 cal yr BP (Lavariškės palaeobasin) or 9400 cal yr BP (Briaunis palaeobasin) and populated southeastern Lithuania at similar time (Pakampis). A nut-tree is resistant to seasonal draughts, severe winters and cool summers (Huntley, 1993). Thus, its occurrence along with other species indicates continental climatic conditions. Then, an average July temperature might have reached c.15°C (Hoffmann et al., 1998). The findings of *Lycopus europaeus* fruits support the fact that an average July temperature was no lower than 16°C (Bell, 1970). A seed of spruce (*Picea* sp.) may indicate the presence of coniferous-deciduous forests even though only 3 % of spruce pollen was found in the area. A local expansion of the spruce into the study area had happened later, c. 8900–8700 cal yr BP, according to the results of pollen investigations.

The improving climate conditions were favorable for the *Tilia* expansion. Lime-trees appeared at c. 9200 cal yr BP in the eastern (Briaunis, Lavariškės) and southeastern (Pakampis) regions of Lithuania. *Tilia* sp. macrofossils in the sediments of the Lavariškės palaeobasin dated at c. 8900 cal yr BP point out toward the climate warming and predominance of those trees in the surrounding. *Tilia* had already reached Dūba and Pelesa Lakes in southeastern Lithuania by that time (Stančikaitė et al., 2002). The presence of lime-trees of similar time was fixed in southeastern Latvia (Heikkilä et al., 2009) and northern Estonia (Punning et al., 2003). This tree used to occupy the areas with humus- and-mineral rich soils. Such conditions prevailed in the Briaunis and Pakampis areas as was confirmed by the LOI investigations indicating only small presence of clastics in the sediments. Oak-trees immigrated into the Briaunis Lake area along with nut-trees and limes by the end of the period. They started to grow in southeastern Lithuania at similar time (Stančikaitė et al., 2002).

Alders started to colonize many of the wet palaeobasin shores. The fast expansion of alder in Europe was caused by the climate changes (Huntley and Birks, 1983; Saarse et al., 1999). Their first appearances were found in the surrounding of the Briaunis, Lavariškes and Pakampis palaeobasins. Their local distribution was confirmed by appearance of alder macrofossils in the Briaunis and Pakampis sediments. Alder has immigrated into southwestern Lithuania at similar time (c. 9500 cal yr BP) (Balakauskas, 2012) but did not reach eastern Lithuania until c. 8200–8000 cal yr BP (Gaidamavičius et al., 2011). Appearance of this tree is usually related to an expansion of dump, fertilizer-rich habitats (Hannon and Gaillard 1997; Miotk-Szpiganowicz and Niska 2008). *Alnus glutinosa* is highly adapted to such habitats because it can stand oxygen-deficient conditions in soaked-up soils. The species could have been responsible for the nitrogen increase and pH decrease in soils (Hannon and Gaillard, 1997). Nitrophylic species such as *U. dioica* can appear together with *A. glutinosa* as it was recorded in the vicinity of the Pakampis water basin. A variety of herbaceous plants and their amount have degraded in the study area because of the changing forest composition and expanding deciduous trees.

A water level did not change much in majority of the palaeobasins (Lavariškės, Verpstinis, Pakampis) except for the Briaunis water basin where slight variations of water level were observed. A noticeable decrease in numbers of plankton and bottom species *Navicula oblonga* c. 9600 cal yr BP might be explained by a drop of water level. Meantime, the *Cyclostephanos dubius* species found in the sediments is often related to an increased water salinity and incipient eutrophication of water basins (Stoermer et al., 1987). The latter process is also indicated by the *Najas*, *Nymphaea alba* and *Ceratophyllum demersum* macrofossils. The presence of latter species in sediments also shows that the palaeobasin water was enriched by carbon (Kłosowski et al., 2011). Numerous findings of bottom diatom species are good indicators of transparent, nutrient-rich waters.

A water level had dropped by c. 9100 cal yr BP in the Briaunis palaeobasin. This was proved by the expansion of dump habitats predominated by alders. The results of diatom algae studies showing the decrease of planktonic and bottom species to a minimum and predominance of epiphytic species pointed out to a water level drop and overgrowing of shores. A low water level in Lithuania was also fixed during the earlier investigations (Kabailienė, 2006). The data indicating a low water level in central Europe c. 9100–9000 cal yr BP are usually assigned to one of the pre-boreal climate oscillations (Jakab et al., 2004; Magny, 2004; Magyari et al., 2009). In the period under consideration, c. 8800 cal yr BP, a water level of Verpstinis Lake rised up again, what was implied from the decreased amount of marshy areas and coastal plant variety. The latter data contradicts the former data about the low water level; however such disagreement can be explained by dating errors or specific local conditions. A rise of water level at similar time was also described in neighboring Poland (Gałka et al., 2014), what again can be explained by the local conditions. Sparse *Potamogeton* sp. and *P. natans* species in the Verpstinis palaeobasin are usually resistant to variations of water levels. They can dwell down to 6 m depth (Hannon and Gaillard, 1997). Meantime, plants that do not require fertile soils (e.g. *Andromeda polifolia, Oxycoccus* sp. and *Rynchospora alba*) dwelled in the wetlands. Their expansion is related to the formation of moor communities (*Oxycocco–Sphagnetea* and *Scheuchzerio–Caricetea nigrae)*.

At similar time c. 8400 cal yr BP, water plants disappear from the Lavariškės palaeobasin. Meanwhile a number of wetland and coastal plants increases. The latter fact has indicated an intense overgrowing and wetland expansion in the region. The process continued through the whole Holocene. A mixed moor combining both the upland and lowland moor vegetations was emerging according to the dominating vegetation. Moors and bogs have been formed at that time elsewhere in Lithuania (Kabailienė, 2006). Likely the process was caused by the increased climate humidity.

Middle Holocene (8200 – 4200 cal yr BP)

A following stage of environmental development, the so-called Holocene climatic optimum which had started c. 8000 cal yr BP, in the eastern Baltic region was marked by the increased humidity, precipitation and higher average annual temperature (Seppä and Poska, 2004). That had affected the existing vegetation and palaeoenvironments very much. Forests of different composition had populated distinct areas.

At the beginning, more deciduous trees, especially *Ulmus* and *Tilia*, had forested fertile soils of the eastern (Briaunis and Lavariškės) and southeastern (Pakampis) regions. The highest population of those species was fixed in the area of the Lavariškės palaeobasin at that particular time. *Tilia* thrived at c. 7600 cal yr BP, whereas *Ulmus* has reached its maximum at c. 7500 cal yr BP. However these forests were still not dense allowing a nut-tree to expand in the area (Miotk–Szpiganowicz and Niska, 2008). That was indicated by a great number of *Corylus* pollen in southeastern (Pakampis) and eastern (Briaunis, Lavariškės and Verpstinis) Lithuania. Alders (*Alnus*) dwelled in the dump habitats. Lime-trees (*Tilia*) reached the already existing forests of Verpstinis area at c. 7700–7400 cal yr BP. Such a late arrival of lime-tree into the area can be explained by the unfavorable edaphic conditions in that region. It seems that the area dominating soils were unsuitable for a lime-tree to grow. Lime-trees usually grow in fertile soils, whereas the soils with medium nitrogen content prevailed in the habitats of that time.

Deciduous trees populated the birch-pine forests, which had already established in the palaeobasin surroundings in northwestern Lithuania (Pakastuva): nut-trees c. 8100 cal yr BP, elms, alders and lime-trees c. 8000 cal yr BP, and oaks c. 7100 cal yr BP (Macijauskaitė, 2012). An arrival of lime-trees and oaks at similar time was described in the earlier publications (Stančikaitė et al., 2006). The palaeobasin of that time in the northwestern region was quite shallow, reaching only 2 m. It was populated by *N. marina* and *N. alba*, while *Typha* sp dwelled on the shallower shores. The population of the above species can indicate that the habitats were mineral, especially nitrogen rich.

The vegetation has stabilized in the Briaunis palaeobasin by the period of 7900–7200–7100 cal yr BP. The findings of *Cladium mariscus* and *N. marina* macrofossils in the Lake sediments evidence the climate warming, which in Lithuania and the neighboring regions are assigned to the climate optimum (Marek, 1991; Tobolski et al., 1997; Lang, 1994; Stančikaitė et al., 2004; Tobolski, 2006; Brande, 2008). A water level was dropping allowing the plants of bogs and shores to thrive. Notwithstanding the increased humidity in the Briaunis Lake surroundings, a variety of planktonic diatom species had considerably decreased at that time, what, in turn, indicated a much lower water level. A decreased number of bottom diatom species had evidenced that the water was muddy and almost non-transparent for sun rays. Meantime, the alkaline water with a great number of epiphytic diatoms, i.e. *Fragilaria* species, supported the fact that conditions were similar as described above (Bigler et al., 2006). The dominating species of water plants (*Myriophyllum verticillatum*, *P. natans*, *P. perfoliatus*, *N. marina*, and *N. alba*) and characteristic diatom complexes (*Fragilaria pinnata*, *Fr. construens* spp., *Fr. brevistriata*, *Fr. dilatata*, *Navicula digitoradiata* and *N. oblonga*) (Gryguc et al., 2013) dwelled in the waters with neutral pH (Ellenberg et al., 1991; Hannonand Gaillard, 1997), in the eutrophic conditions. *N. marina* usually prefers carbonate-rich shallow waters (Ozola et al., 2010). The high carbonate content in the studied water was confirmed by the results of LOI investigations.

Later, the highest throughout the Holocene pollen content of thermophylic trees (*Ulmus*, *Tilia*) was fixed in the basin sediment. Meanwhile, those trees started to retreat from the Lavariškės forest. A spruce gradually immigrated into the eastern Lithuanian region (Lavariškės) c. 7300 cal yr BP. It became a very important component of those forests. Meantime, a spruce re-immigrated into eastern Lithuania at c. 7300–6800 cal yr BP (Gaidamavičius et al., 2011). A decreased number of *Corylus* pollen as well as a small amount of herbaceous plants in the studied sediments have indicated that open areas degraded and dense forests were characteristic for that time (Miotk–Szpiganowicz and Niska, 2008). Meantime, the greatest number of *Alnus* pollen in the Briaunis Lake sediments was fixed. A reasonably high number of *Alnus* pollen was detected also in the spectra of other study objects. The sudden *Alnus* expansion throughout Europe was caused by the climate changes (Saarse et al., 1999). The dominance of thermophylic trees and alder pointed out to the warm and humid climate (Kabailienė, 2006). A great number of *A. glutinosa*, *Betula* sect. *Albae* and *B. pubescens* macrofossils evidences a local distribution of those plants around lakes.

Surroundings of the lakes started to overgrow at c. 7200–7100 cal yr BP as was indicated by the increase in organics (363 cm depth) and macrophyts (*N. alba*, *N. marina*) in the Briaunis palaeobasin. According to the results of plant macrofossil and diatom investigations, a low water level was reconstructed for the lake. The water basin was highly eutrophic, what was evidenced by numerous *Amphora* species which usually require very high amount of nutrients (Van Dam et al., 1994) and a great amount of *Cyclostephanos dubius* remains. Voluminous *S. lacus*tris and *Carex* sp. macrofossils have indicated that those herbaceous plants dominated the coastal areas. The *L. trisulca* macrofossils may indicate a high calcium content in the eutrophic basin of that time (Szoszkiewicz et al., 2010). Oscillations of water level may have provoked the surface degradation and voluminous input of terrigenic matter into the sediments. Even negligible water rise at c. 6600–6500 cal yr BP has caused the extinction of *Schoenoplectus lacustris* which is typical for shallow water basins (Hannon and Gaillard 1997). Species of xeromesophytes with numerous macrofossils of *Urtica dioica* were widespread at the same time. Nettles as nitrophylic species usually dwells around water basins in edaphic conditions indicating an intense carbonate loss. The latter fact was confirmed by the results of LOI investigations. A water level rise was observed elsewhere in central Europe at the same time (Magny, 2004). Meantime, the increase in number of *Lemna trisulca* macrofossils was caused by the increasing water temperature. The temperature is crucial for flowering of that plant and its ability to bear fruits. Usually *Lemna* sp. flowers when a temperature of 25°– 30°C remains not less than for 14 days (Stachowicz-Rybka, 2009; Szczepanek, 1971). Thus, the finds of *L. trisulca* are evidences of quite high average summer temperatures. For comparison, nowadays the similar summer temperatures in eastern Lithuania stay for c. 16–18 days (Bukantis, 1998). In the period under consideration, c. 6600 cal yr BP, an increased number of *N. marina* macrofossils and appearance of *Nuphar lutea* in the Pakastuva palaeobasin can be related to the warming climate. Water plants disappeared from the Verpstinis basin c. 6100 cal yr BP after a water level had dropped. Sedges occupy the wet basin shores with high abundances of *Carex* sp. and *C. elata*.

Later, c. 5700 cal yr BP a number of thermophylic plants such as *Ulmus* and *Tilia* started to decrease in the study area. A spruce started to expand in the northwestern region of Lithuania and culminated at about c. 4700 cal yr BP. This species has dominated almost all Lithuania at that time (Balakauskas, 2012). Alders thrived around the water basins. Meantime, oaks had advanced into the eastern and southeastern regions of Lithuania. Such a late advance of oaks can be explained by the presence of specific edaphytic conditions of mentioned areas. A number of dump habitats had decreased c. 5100 cal yr BP in the northwestern region. Pine-forests dwelled in the sandy, dry soils and semi-simultaneously the areas of spruce-forests expanded. A pollen number of herbaceous plants such as Poaceae and Cyperaceae have increased considerably. Open places were likely to form in this region. A productivity of Pakampis Lake increased c. 5700 cal yr BP when a water level had dropped. The latter fact is supported by the appearance of *N. marina*. This plant usually dwells down to 2 m depth (Hannon and Gaillard, 1997). The coastal vegetation remains poor. Areas of the nitrophylic habitats that were dominated by *U. dioica* had expanded. Semi-simultaneously, *N. marina* had considerably decreased and *N. lutea* had completely disappeared from the Pakastuva palaeobasin. A variety of coastal plants and a number of wetlands had gradually increased. Sedges (*C. distans*, *C. echinata*, *C. pseudocyperus* and *Carex* sp.), *L. europaeus* and *Menyanthes trifoliata* had populated the area. Later, c. 5400 cal yr BP the water plants disappeared because of a water level drop. The subsequent water drop was also observed in northeastern Poland (Ralska-Jasiewiczowa and Latałowa, 1996; Gałka et al., 2013a; Gałka and Apolinarska 2014), northern Estonia (Punning et al., 2003), and southern Sweden (Digerfeldt, 1998). The voluminous *U. dioica* macrofossils show that the nitrogen-rich habitats had expanded. The water level elevation likely caused an appearance of *N. alba* in the palaeobasin c. 4600 cal yr BP. At similar time, c. 4400 cal yr BP the water level had elevated also in Purwin Lake of northeastern Poland (Gałka and Apolinarska, 2014) and in Iso Lehmälampi Lake of southern Finland (Sarmaja-Korjonen, 2001).

Late Holocene (4200 cal yr BP and until present)

When the period started in the eastern Baltic region, the precipitation was high while average annual temperature was low (Seppa and Poska, 2004). Open places had dominated the landscape while a number of deciduous trees had decreased. Forests of the eastern (Lavariškės) and northwestern (Pakastuva) regions of Lithuania were occupied with coniferous trees (pines and spruces), and minor birch-trees. Similar vegetation was characteristic also for the Verpstinis palae-basin environs of that time (Gaidamavičius et al., 2011). A spruce immigrated into the southeastern region of Lithuania (Pakampis Lake) c. 3600 cal yr BP. Such the later advance of a spruce can be explained by the local climatic conditions. Alders and nut-trees dwelled onshore of the palaeobasins. Areas of habitats suitable for herbaceous plants expanded after the forests had thinned. The observed changes in vegetation evidenced the cooling of climate. Pines had forested eastern (Lavariškės) and southeastern (Pakampis) Lithuania later, c. 2600 cal yr BP. The findings of *Cereale* pollen and increased number of herbaceous plants (Poaceae, Cyperaceae, *Artemisia*) in the Pakampis Lake sediments may indicate incipient human activities.

Meantime, c. 4200–4000 cal yr BP, the Pakastuva Lake was only 2 m deep, what was implied from the findings of water plant species (*Chara* sp., *P. praelongus*, *P. natans* and *P. pusillus*) and *Cristatella mucedo* statoblasts in the studied sediments. The latter species is considered to be a good indicator of water temperature. It usually dwells in those water basins where the water temperature is 11–16 °C (Okland and Okland, 2000). According to the preserved plant macrofossils (*Eleocharis palustris*, *Ranunculus sceleratus* etc), the Briaunis water level was extremely low at that time. The fact that the sediments were forming far from the shoreline was supported by the voluminous *Scirpus sylvaticus* macrofossils. Their environment was still humid because such plants as *Comarum palustre*, *M. trifoliata* etc were still present. It's likely that areas around the Briaunis Lake turned into moors where sedges (*Carex* sp.) had thrived. However, the plants of dryer habitats had occurred along with the described above. The similar environmental conditions around the Briaunis Lake prevailed until 3600–3400 cal yr BP. The later disappearance of marshy places and coastal plants was likely caused by the water level elevation. Similar changes related to the water level elevation were fixed in the basins of central Europe (Magny, 2004), Poland (Gałka et al., 2014), Finland (Heikkilä and Seppä, 2003; Väliranta et al., 2007), and Estonian lakes (Punning et al., 2003). These changes were caused by the increased precipitation accompanied with cool climate that were reported in the eastern Baltic region (Seppä and Poska, 2004). The formation of bogs in the Verpstinis palaeobasin has intensified from 3000 cal yr BP. A number of macrofossilsof shrubs (*A. polifolia* and *Oxyccocus* sp.) and herbaceous plants (*R. alba*) had increased in the study area. Areas of sedges (*Carex* sp., *C. elata*) gradually degraded. According to the dominating plant species, the area had oligotrophic conditions and a low pH. Such conditions were a case why the flora was so poor in the study area. The Pakampis palaeobasin started to overgrow by macrophyts c. 3100 cal yr BP. A number of *N. alba* and *N. marina* macrofossilshad increased considerably. A water level did not change. The palaeobasin might have been 2 m deep (Hannon and Gaillard, 1997) according to the present species of water plants. The degradation of areas of fertile soils can explain why less of *Urtica* and *Alnus glutinosa* macrofossils had been found. Subsequently, a variety of coastal and wetland plants had increased. The later drop of water level had caused the immigration of *E. palustris* and disappearance of water plants. *E. palustris* usually dwells down to 30 cm depth (Szoszkiewicz et al., 2010), however can withstand oscillations of a water level to 50–100 cm (Hannon and Gaillard, 1997). Majority of the water basins turned into moors and were overgrown according to the predominating flora.

To sum up:

a) The vegetation of forest-tundra predominated during the short-lived climate warming (GI-1e climatic event). At the beginning, the water basins had a high water level and low degree of eutrophication and were enriched in carbonates. Later, the climate has cooled and humidity decreased (GI-1d climatic event). These conditions were favorable for herbaceous plants to grow. The basins remained high in water and poor in nutrients. Environmental conditions had drastically changed during the GI-1(c-a) climatic event. Thin pine-birch forests populated the area after the climate had warmed and sol cover had stabilized. Surroundings of the Rudnia palaeobasin were populated by a spruce. The basins had a moderate water level, medium-warm water and high amount of biogenic matter. The short-lived climate cooling (Gerzencee oscillation) caused the recession of the thin forests. Erosion processes frequented the area. Later, during the GI-1a climatic event the sedimentation in the Rudnia basin has stopped because of aeolian processes. Tundra and forest-tundra plants replaced the thin forests and populated the area when climate had cooled and dried during the GS-1 climatic event. Subsequently, a water level has risen in the Zervynos palaeobasin leading to the decrease of nutrients.

The basin sedimentation has stopped completely by the end of the period because of aeolian processes.

b) Birches followed by pines have advanced into open places when the climate had warmed during the early Holocene. A spruce appeared in Lithuania. The forests had differentiated. Elms, nut-trees, lime-trees, oaks and alders slowly immigrated into the study area. The studied palaeobasins of that time were shallow and none-productive except for the Briaunis and Verpstinis palaeobasins with a high water level. Later oscillations of a water level in the palaeobasins lead to more intense eutrophication processes. Moors started to advance in the area after the humidity had increased by the end of the period. Dense, mixed forests dwelled in the area during the middle Holocene when the climate had warmed and humidity had increased. The deciduous forests had degraded and subsequently spruces had invaded the northwestern region during the second half of the period. Meantime, the palaeobasins were shallow; however their water level oscillated frequently. They started to overgrow and turn into moors. The landscape featured more open places in the late Holocene. The palaeobasins were shallow. They rapidly overgrew by plants and turned into moors.

CONCLUSIONS

1. Plants of the *Charetea fragilis* and *Potamogetonetea pectinati* communities dominated water basins of the Lateglacial and Holocene, while the *Lemnetea minoris* communities appeared when the climate had warmed. The shores were populated by a small number of communities in the Lateglacial; whereas those communities effloresced in the Holocene. Surroundings of the palaeobasins at that time were populated by the communities characteristic for moors (*Oxycocco-Sphagnetea*, *Scheuchzerio-Caricetea nigra* and *Alnetea glutinosae)*, water basins and shores (*Phragmito-Magnocaricetea* and *Bidentetea tripartitae),* meadows (*Molinio-Arrhenatherea* and *Nardetea strictae),* agricultural land *(Artemisietea vulgaris)*, outer woods, cuttings and fireplaces (*Epilobietea angustifolii*).
2. The Ellenberg's system for the evaluation of modern environmental conditions allowed to evaluate the palaeo-environmental conditions and to reconstruct the conditions in which plant communities had dwelled during the Lateglacial and Holocene time
3. Based on the Ellenbergs' system the following conclusions describing the ecological situation in the habitats that existed within the basins follows – during the Lateglacial the temperature in the mostly habitats varied between cool and fairly warm; pH reaction was neutral; in mostly habitats indicators of medium nitrogen and nitrogen-rich soils predominated suggesting rather high presence of nitrogen in environment. For the Holocene interval habitats varying between the fairly warm - warmth conditions flourished; with the pH varying from the neutral to alkaline reaction and predominance low nitrogen - nitrogen rich soils.
4. During the Lateglacial plants typical for the fairly warm - warmth conditions and predominating in the medium nitrogen and nitrogen-rich soils with the medium acidic- alkaline reaction flourished onshore of investigated basins. For the Holocene vegetation high representation of the plants typical for the fairly warm - warmth temperature regime with the broad scale of acidic preferences (from acidic to neutral) and requirements for the soil nitrogene (from low-nitrogene to nitrogene-rich) should be pointed out.

5. The GI-1(c-a) climatic event is characterized by the greater variety of water, wetland and coastal plant species compared to other times. Appearance of the *Potamogeton filiformis* and *Selaginella selaginoides* species during the GI-1b climatic event coincided with the globally fixed, short-lived climate cooling (GI-1b- "*Gerzensee oscillation*"). This oscillation was observed in the region for the first time.
6. In the Holocene, the accelerating process of eutrophication in the palaeobasins has facilitated their overgrowing by macrophyts and the development of moors. The process has intensified in the late Holocene. The plant complexes comprising *Nymphaea alba*, *Najas marina*, *Menyanthes trifoliata, Schoenoplectus lacustris* etc usually appear when the water basin starts to overgrow, while the plant complexes of *Andromeda polifolia*, *Oxycoccus* sp., *Vaccinium* sp., *Rhynchospora alba* etc are characteristic for wetlands and moors.

VĖLYVOJO LEDYNMEČIO IR HOLOCENO AUGALIJOS RAIDOS YPATUMAI NUOSĖDŲ PALEOBOTANINIŲ TYRIMŲ DUOMENIMIS

SANTRAUKA

Daugelis Lietuvos teritorijoje vykdytų vėlyvojo ledynmečio ir holoceno paleoaplinkos tyrimų buvo paremti palinologinės analizės duomenimis. Pagrindinis dėmesys buvo skiriamas augalijos dinamikai regione, nes dėl šio metodo galimybių yra apribota vietinės augalijos ypatybių analizė. Siekiant užpildyti šią spragą buvo pasitelkti augalų makroliekanų tyrimai. Vėlyvojo ledynmečio ir holoceno laikotarpio augalijos istoriją iliustruojančių augalų makroliekanų tyrimų duomenų, pagrįstų absoliutaus amžiaus datavimais vis dar stokojama ir ypač tai liečia Lietuvos teritoriją.

Paleoaplinkos sąlygų atkūrimui ypač svarbūs augalų makroliekanų tyrimai, kurie padeda geriau suprasti vėlyvojo ledynmečio ir holoceno metu vykusius paleoaplinkos pokyčius: klimatinius, hidrologinius, dirvodarinius bei biotinius. Iki šiol taikyti metodai neleido objektyviai rekonstruoti paleopalinkos sąlygų. Augalų makroliekanų tyrimų taikymas leido padaryti tikslesnės išvadas apie betarpišką augalijos plėtrą teritorijoje, atskirų augalų rūšių įmigraciją į teritoriją bei įvertinti rūšinę augalijos sudėtį. Vykdant šiuos tyrimus atsirado galimybė charakterizuoti tiek vandens baseinuose, tiek ir sausumos aplinkoje vykusias permainas. Augalų makroliekanų datavimas AMS padėjo pagrindą tikslesnei chronologijai ir leido nustatytus klimatinius įvykius koreliuoti su fiksuojamais globaliais bei regioniniais pokyčiais.

Šio darbo tikslas – kompleksinių tyrimų pagrindu charakterizuoti augalijos raidos ypatumus vėlyvajame ledynmetyje ir holocene. Tikslui pasiekti, buvo sprendžiami šie uždaviniai: atlikti pelkinių-ežerinių nuosėdų pjūvių augalų makroliekanų analizę, augalų makroliekanų tyrimų pagalba charakterizuoti vietinės augalijos pobūdį bei jos kaitą, nustatyti atskirais paleobaseinų vystymosi etapais susiformavusius augalų paleobendrijų kompleksus, remiantis Ellenbergo šiuolaikine aplinkos sąlygų vertinimo sistema tirtose vietose charakterizuoti augalų buveinių ekologinės sąlygas, bei kompleksinių tyrimų rezultatų pagrindu atlikti paleoekosistemos rekonstrukciją ir fiksuoti vėlyvajame ledynmetyje ir holocene vykusius aplinkos pokyčius.

Nuosėdų tyrimai buvo atlikti 7 objektuose: Briaunio, Verpstinio, Pakampio, Pakastuvos ežeruose, Lavariškės pelkėje bei dviejose Ūlos upės (Zervynai, Rudnia) atodangose. Tyrimų objektai išsidėsto Paskutinio apledėjimo fliuvioglacialinių lygumų bei Paskutinio apledėjimo moreninių aukštumų srityse.

Disertacinis darbas pagrįstas augalų makroliekanų analizės bei chronologinių metodų duomenimis. Duomenų interpretacijai pasitelkti ir palinologinių, nuosėdų medžiaginės sudėties (LOI), izotopinių ($\delta^{18}O$ ir $\delta^{13}C$) tyrimų rezultatai.

Apibendrinus autorės atliktų tyrimų rezultatus galima teigti, kad:

1. Vėlyvojo ledynmečio ir holoceno metu vandens baseinuose vyravo *Charetea fragilis* ir *Potamogetonetea pectinati* bendrijos, o klimatui atšilus paplinta ir *Lemnetea minoris* bendrijos augalai. Tuo tarpu pakrantėse vėlyvojo ledynmečio laikotarpiu įsikūrusios paleobendrijos buvo gan skurdžios, tačiau holoceno metu pastebimai pagausėjo rūšių įvairovė. Tuo metu paleobaseino aplinkoje augusi augalija buvo būdinga pelkių (*Oxycocco-Sphagnetea*, *Scheuchzerio-Caricetea nigrae, Alnetea glutinosae)* vandens telkinių ir jų krantų (*Phragmito-Magnocaricetea*, *Bidentetea tripartitae),* pievų (*Molinio-Arrhenatheretea, Nardetea strictae),* dirbamų laukų *(Artemisietea vulgaris)* bei pamiškių, miško aikštelių, gaisravečių, kirtaviečių (*Epilobietea angustifolii*) bendrijoms.
2. Ellenbergo šiuolaikinių aplinkos sąlygų vertinimo sistema leido įvertinti paleoaplinkos sąlygas bei atkurti vėlyvojo ledynmečio ir holoceno metu vyravusių augalų buveinių ekologinės sąlygas. Remiantis Ellenbergo šiuolaikinių aplinkos sąlygų vertinimo sistema vėlyvajame ledynmetyje susiformavę paleobaseinai dažniausiai buvo tarpinės tarp šaltų ir vidutinio šiltumo, beveik neutralios reakcijos, tarpinės tarp mažo ir vidutinio azotingumo buveinės. Tuo tarpu holoceno laikotarpiu vyravo tarpinės tarp vidutinio šiltumo ir šiltų, beveik neutralios arba šarminės reakcijos, nuo mažo iki azotingo dirvožemio buveinės.
4. Vėlyvajame ledynmetyje paleobaseinų pakrantėse vyravo tarpinių tarp vidutinio šiltumo ir šiltų, nuo vidutinio rūgštingumo iki šarminės reakcijos, nuo vidutinio azotingumo iki azotingų buveinių augalai. Holoceno laikotarpiu paleobaseinų pakrantėse augo tarpiniai nuo vidutinio šiltumo iki šiltų, nuo rūgščios iki beveik neutralios reakcijos, nuo mažo azotingumo iki labai azotingų buveinių augalai.

5. GI-1(c-a) klimatinis įvykis lyginant su kitais išsiskiria didesne vandens, pelkėtų vietų ir pakrančių augalų rūšine įvairove. GI-1b klimatinio įvykio metu užfiksuotas šaltamėgių rūšių *Potamogeton filiformis* ir *Selaginella selaginoides* pasirodymas sutapo su globaliai fiksuojamu trumpalaikiu klimato atšalimu (GI-1b- Gerzensee oscilacija), kuris iki šiol regione nebuvo stebimas.
6. Holoceno laikotarpiu paleobaseinuose intensyvėjantis eutrofikacijos procesas skatino vandens baseinų užaugimą makrofitais bei pakrančių pelkėjimą, kuris ypač išryškėjo vėlyvajame holocene. Augalijos kompleksai su *Nymphaea alba*, *Najas marina*, *Menyanthes trifoliata, Schoenoplectus lacustris* ir kt. charakterizuoja prasidėjusį užaugimo procesą; pelkėjimo procesą rodo kompleksas su *Andromeda polifolia*, *Oxycoccus* sp., *Vaccinium* sp., *Rhynchospora alba* ir kt.

Disertacinį darbą sudaro įvadas, ankstesnių augalų makroliekanų tyrimų apžvalga, poledynmečio nuosėdų stratigrafija, tyrimų objektai, gamtinė aplinka, tyrimų metodai, tyrimų rezultatai, diskusija, išvados, literatūros sąrašas ir priedai. Darbe pateikiama 22 paveikslai ir 35 lentelės. Darbo apimtis 182 puslapiai.

LIST OF PUBLICATIONS

Gaidamavičius A., Stančikaitė M., Kisielienė D., Mažeika J., **Gryguc G., 2011.** Post-glacial vegetation and environment of the Labanoras Region, East Lithuania: implications for regional history. *Geological Quarterly* 55 (3), 269–284.

Gryguc G., Kisielienė D., Stančikaitė M., Šeirienė V., Skuratovič Ž., Vaitkevičius V., Gaidamavičius A., **2013.** Holocene sediment record from Briaunis palaeolake, Eastern Lithuania: history of sedimentary environment and vegetation dynamics. *Baltica* 26 (2), 121–136.

Zernitskaya V., Stančikaitė M., Vlasov B., Šeirienė V., Kisielienė D., **Gryguc G.**, Skipitytė R., **2014.** Vegetation pattern and sedimentation changes in the context of the Lateglacial climatic events: Case study of the Staroje Lake (Eastern Belarus). *Quaternary International* xxx, 1–13. http://dx.doi.org/10.1016/j.quaint.2014.06.045

Stančikaitė M., Šeirienė V., Kisielienė D., Martma T., **Gryguc G.**, Zinkutė R., Mažeika J., Šinkūnas P., **2014.** Lateglacial and early Holocene environmental dynamics in northern Lithuania: A multi-proxy record from Ginkūnai Lake. *Quaternary International* xxx, 1–14. http://dx.doi.org/10.1016/j.quaint.2014.08.036

Veski S., Seppä H., Stančikaitė M., Zernitskaya V., Reitalu T., **Gryguc G.**, Heinsalu A., Stivrins N., Amon L., Vassiljev J., Heiri O., **2014.** Quantitative summer and winter temperature reconstructions from pollen and chironomid data between 15–8 ka BP in the Baltic–Belarus area. *Quaternary International* xxx, 1–8. doi:10.1016/j.quaint.2014.10.059

CURRICULUM VITAE

Gražyna Gryguc

ADDRESS

Institute of Geology and Geography
Nature Research Centre
Akademijos str. 2
Vilnius LT-08412
Phone: +37067701034
E-mail: grazyna.gryguc@geo.lt

Date and place of birth: 14 August 1984, Suwałki, Poland

Education:
2011–2014 PhD student in Nature Research Centre, Institute of Geology and Geography

2007–2009 Vilnius University, the Faculty of Natural Sciences Master's graduate (botanist).

2003–2007 Vilnius University, the Faculty of Natural Sciences Bachelor's graduate (Biologist).

Professional experience:

2010– till now – engineer of the Quaternary Research Laboratory, Nature Research Centre.

Participation in the scientific research:

International

2007–2009 "Nordic Network of Palaeoclimatology investigations"

2011–2013 „Biotic Response to Climate Change in Cold Climates"

National

2010–2011 „The Effect of Anthropogenic Factors on the Development of Invasive Species in Holocene in the Context of Development of Palaeoecosistem". Leading scientist dr. Miglė Stančikaitė.

2012–2014 „Expansion of palaeovegetation in context of the postglacial ecosystem dynamics in the Eastern Baltic".Leading scientist dr. Miglė Stančikaitė.

Training courses:

Nowember 07–18 2011, Department of Environmental Sciences, University of Helsinki, Finland

May 6–20 2012, Department of Plant Ekology, University of Gdańsk, Poland

June 17–21 2012, Department of Post-glacial Geology, University of Tallinn, Estonia.

Participation in the scientific conferences:

Gryguc G., Stančikaitė M. 2008. Post-glacial vegetation history in Northern Lithuania: preliminary results of a pollen survey from Talša lake. *Nordic network of Palaeoclimatology*: second conference, September 26–27, Backagården, Höör, Sweden.

Gryguc G., Kisielienė D. Stančikaitė M., Daugnora L. Blaževičius P., **2011**. Complex bioarchaeological investigations in Vilnius lower castle: history of urban environment. *4th International Conference of the Polish Association for Environmental Archaeology*. September 5–10, 2011, Gdańsk, Poland.

Gryguc G., Stančikaitė M., Kisielienė D., Šeirienė V., **2011**. Development of Šventas lake throughout Holocene according to palaeobotanical data. *1st Biotic response to climate change in cold climates (BioCold)*. September 28–30, Palmse, Estonia.

Gryguc G., Stančikaitė M., Kisielienė D., Šeirienė V., **2011**. Augalijos raida Švento ežere ir jo apylinkėse per pastaruosius 11500 metų paleobotaninių tyrimų duomenimis. *Bioateitis: gamtos ir gyvybės mokslų perspektyvos.* Gruodis 7d., Vilnius.

Gryguc G., Stančikaitė M., Kisielienė D., Šeirienė V., **2012.** Post-glacial environmental changes in Šventas lake region. *INTIMATE INTegrating Ice core, Marine and TErrestrial records: Climate and environmental change from 60,000–8000 years ago, INTIMATE Workshop*. March 25–28, De Lutte, The Netherlands.

Gryguc G., Gaidamavičius A., Stančikaitė M., **2012**. Post-glacial environmental variations in Verpstinis lake, Eastern Lithuania. *2st Biotic response to climate change in cold climates (BioCold) workshop*, April 25–27, Kernavė, Lithuania.

Gaidamavičius A., Stančikaitė M., Kisielienė D., Mažeika J., **Gryguc G., 2012.** Post-glacial environmental of Lithuania: new data from paleobotanical investigation. *2st*

Biotic response to climate change in cold climates (BioCold) workshop. April 25–27, Kernavė, Lithuania.

Gryguc G., 2013. Post-glacial environmental changes derived from the lake sediments of the Eastern part of Lithuania. *BioCold Workshop*, April 23–26, Tovetorp, Sweden.

Kisielienė D., Stančikaitė M., Zabiela G., **Gryguc G., 2013**. Archaeobotanical data from Klaipėda Castle (west Lithuania): peculiarities of the subsistence economy and environmental pattern. *16th Symposium of the InternationalWork Group for Palaeoethnobotany*. June 17–22, Thessaloniki, Greece.

Gryguc G., Gaidamavičius A., Stančikaitė M., **2013.** Post-glacial environmental variations in Verpstinis Lake, Eastern Lithuania. *PERIBALTIC (Palaelandscapes from Saalian to Weichselian, south Eastern Lithuania), International Field Symposium*. June 25–30, Vilnius -Trakai, Lithuania.

Skipitytė R., Stančikaitė M., Kisielienė D., Šeirienė V., Šinkūnas P., Kazakauskas V., Katinas V., Mažeika J., **Gryguc G.**, Gaidamavičius A., **2013.** The Late Weichselian Interstadial in SE Lithuania: multi-proxy approach. *PERIBALTIC (Palaelandscapes from Saalian to Weichselian, south Eastern Lithuania), International Field Symposium*. June 25–30, Vilnius - Trakai, Lithuania.

Stančikaitė M., Zernitskaya V., Kisielienė D., **Gryguc G.**, **2013.** The Lateglacial vegetation pattern: from Belarus to the Eastern Baltic. *PERIBALTIC (Palaelandscapes from Saalian to Weichselian, south Eastern Lithuania), International Field Symposium*. June 25–30, Vilnius-Trakai, Lithuania.

Gryguc G., Stančikaitė M., Kisielienė D., Šeirienė V., Šinkūnas P., Kazakauskas V., Katinas V., Mažeika J., Skipitytė R., Gaidamavičius A., **2013**. Vėlyvojo ledynmečio aplinkos raidos bruožai pietryčių Lietuvoje: Ūla-1 atodangos pavyzdžiu. *Bioateitis: gamtos ir gyvybės mokslų perspektyvos*. Gruodis 11d., Vilnius.

Gryguc G., Stančikaitė M., Mažeika J., Gaidamavičius A., **2014.** Postglacial environment in the eastern Lithuania: multi-proxy approach. *The Baltic Sea a Mediterranean of North Europe.* June 4–6, Gdańsk, Poland.

Kisielienė D., Stančikaitė M., Šeirienė V., **Gryguc G.**, Skipitytė R.**, 2014.** Late-glacial climatic events and chronology of environmental development in south-east Lithuania. *The Quaternary of the Urals: global trends and Pan-European*

Quaternary records, INQUA - Section on European Quaternary Stratigraphy. September 10–16, Ekaterinburg, Russia.