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Environmental changes in SW Lithuania during 8720–7990 cal yr BP: analysis of Lake Amalvas sediments

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Abstract. In this paper, we present the results of a high-resolution pollen study covering the 8720–7990 cal yr BP time interval from a well-dated core of lacustrine sediments in Lake Amalvas, southwest Lithuania, supplemented by loss-on-ignition and magnetic susceptibility analyses. The 20–25-year interval between samples allows for a temporally-detailed investigation of changes in sedimentation in the lake's catchment and vegetation in its surroundings. Key findings include a marked increase in magnetic susceptibility and a simultaneous decrease in organic matter values at 8650 cal yr BP, indicating landscape instability due to local hydrological changes. An increase in alder pollen during 8510–8260 cal yr BP suggests heightened humidity, while a slight rise in birch pollen from 8530 to 8430 cal yr BP and a nearly simultaneous decrease in thermophilous tree pollen imply a cooling trend, probably linked to broader climatic fluctuations preceding the 8.2 ka event. Notably, evidence of the 8.2 ka event itself is negligible from the Lake Amalvas sediments, indicating a mild environmental impact in southern Lithuania. The precise dating of the Early Holocene hazel maximum (8640–8590 cal yr BP) and a notable increase in pine pollen between 8200 and 8160 cal yr BP provide valuable regional chronological markers. These findings enhance our understanding of Holocene environmental dynamics in southern Lithuania and offer reference points for future paleoenvironmental research.

Keywords: *Holocene; Boreal; Atlantic; pollen analysis; loss-on-ignition*

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INTRODUCTION

One of the most prominent short-term climatic events that took place during the Holocene is the 8.2 ka event (Alley *et al.* 1997) which occurred due to the drainage of periglacial lakes in North America, causing the imbalance of circulation in the North Atlantic. The event eventually resulted in temperature decrease of up to 1–5°C at different parts of the Northern hemisphere within a few decades and later recovered to previous levels (Veski *et al.* 2004). These changes affected the environment and have left traces in sediments, which can be used to reconstruct these climatic changes. Among the most effective methods for reconstructing climatic changes during short-term events like the 8.2 ka event are pollen analysis and loss-on-ignition. The 8.2 ka event is often traced in the high-resolution lacustrine and bog sequences throughout the world. However, due to a relatively short scale of the event, it is often represented by just one or two samples. Despite a high demand for such data from different regions and settings (Seddon *et al.* 2014), higher-resolution investigations are still rare. They usually involve the analysis of laminated sediments (Veski *et al.* 2004; Pędziszewska *et al.* 2015; Paus *et al.* 2019); however, these are rarely available in post-glacial environments of most regions, including the SE Baltics.

A possible effect of the 8.2 ka event has been observed in the territory of Lithuania (Gryguc *et al.* 2013; Stančikaitė *et al.* 2019); however, the resolution has not been sufficient to confirm this effect with certainty. According to broader research, the effect of the 8.2 ka event should be relatively small or even untraceable in Lithuania (Rohling, Pälike 2005; Seppä *et al.* 2007). To examine the environmental changes around the 8.2 ka event in this region, we investigated the lacustrine sediments whose age had already been established from previous high-resolution studies in Lake Amalvas, SW Lithuania. The Lake Amalvas pollen diagram, consisting of 119 pollen samples and having 20 ^{14}C dates (Juodagalvis, Balakauskas 2012), is one of the best-dated and the most detailed pollen diagrams in Lithuania. To explore environmental changes around the 8.2 ka event with even greater precision, we conducted additional pollen, loss-on-ignition and magnetic susceptibility analyses, along with radiocarbon dating in the segment of the Lake Amalvas sequence covering this event.

Lake Amalvas, a 2 km^2 lake located in SW Lithuania, offers a valuable record of Early Holocene environmental change, particularly in response to regional climatic fluctuations. A lake of this size (which was even larger in the past, considering the area of a vast peat bog around it) predominantly accumulates regional pollen, reflecting broader vegetation patterns rather than local changes (Jacobson, Bradshaw 1981; Prentice 1988). This makes it an ideal site for examining how vegetation in SW Lithuania responded to climate shifts during the time of the 8.2 ka event. Based on the lake's size and sediment composition known from earlier investigations (Juodagalvis, Balakauskas, 2012) it was hypothesized that the vegetation in this region underwent significant changes in response to cooling and hydrological fluctuations during the time interval linked to the 8.2 ka event. Specifically, we expected to see evidence of regional cooling reflected in the increase of minerogenic matter along with shifts in tree populations and/or pollen production, with a possible reduction in thermophilous species and an increase in herb pollen, as well as more cold-tolerant species, such as birch (Tinner, Lotter 2001; Veski *et al.* 2004; Seppä *et al.* 2005; Kofler *et al.* 2005; Wehrli *et al.* 2007; Hede *et al.* 2010; Ghilardi, O'Connell 2013; Stivrins *et al.* 2014; Fiłoc *et al.* 2017).

By leveraging the high resolution of our study, our secondary aim was to examine the acquired data for chronological pollen markers that could be valuable for future investigations.

MATERIALS AND METHODS

Fieldwork and Sampling

Lake Amalvas is a shallow glaciolacustrine lake located in south-west Lithuania, with a surface area of approximately 2 km^2 (Fig. 1) and a maximum depth of around 2.9 m. The lake lies on Weichselian moraine (Guobytė, Satkūnas 2011). It is surrounded by a vast peat bog, extending in all directions from the lake, except south-east, and occupying the area of approximately 36 km^2. It has one major inflow, Šlavanta River, from the east and one major outlet, Amalva, in the south. As reported by the Lithuanian Hydrometeorological Service (LHMT 2024), the annual mean temperature in the study area ranged around 8°C, with an average precipitation of 650 mm, an annual mean wind velocity of 3 m/s, and a dominant westerly wind direction over the period AD 1991 to AD 2020.

The sediments of Lake Amalvas were cored on 24 February 2022, on its northern overgrown bank (WGS84 coordinates: 54°32'12.42" N, 23°34'52.5"E) using a Russian corer. Two pairs of parallel cores with 50% overlap were obtained: one pair using a 100 cm long sampler, 5 cm in diameter (for pollen analysis), and another pair using a 50 cm long sampler, 10 cm in diameter (for dating and loss-on-ignition analysis). All half-cores were packed and taken to the laboratory for sub-sampling. In the laboratory, the half-cores were correlated with each other and divided into 1 cm thick sub-samples for subsequent analyses. Based on the previously dated Amalvas core from the same location (Juodagalvis, Balakauskas 2012), the depths of 376–337 cm were expected to cover approximately 8700–7900 cal yr BP. This interval was subsampled for further paleoenvironmental analyses.

Magnetic Susceptibility Analysis

The measurements of magnetic susceptibility (MS) were carried out for all cores, including the overlapping sections. The total number of analyzed samples was 658, with each sample covering a 1 cm

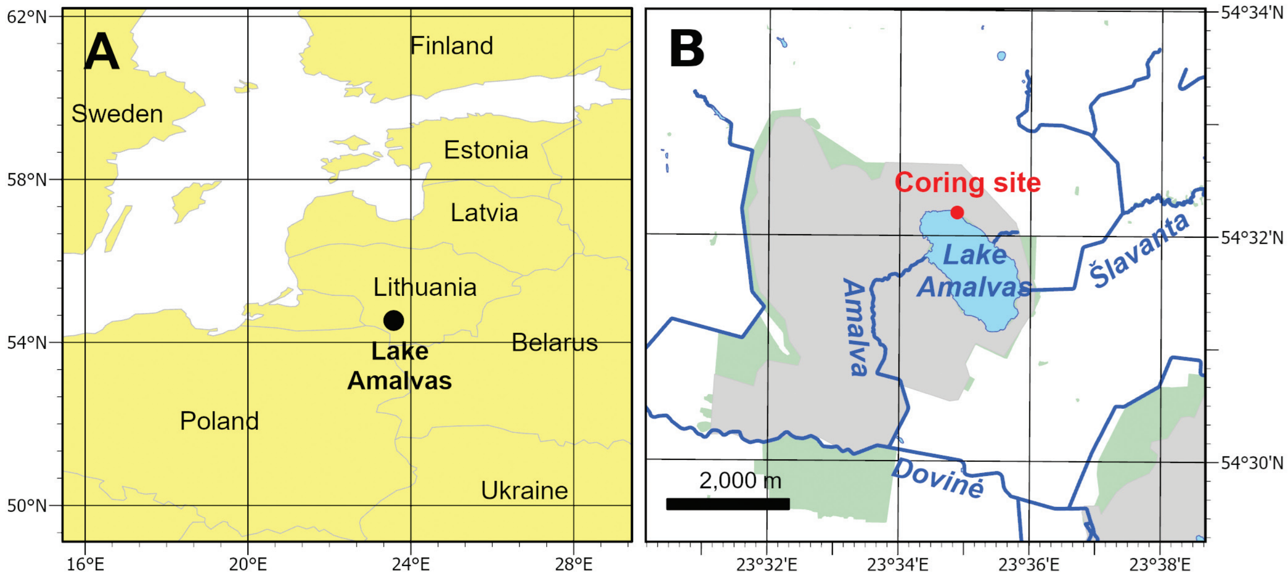

Fig. 1 (A) Location of Lake Amalvas; (B) close-up of Lake Amalvas and its surroundings

thick sediment interval. The analysis was performed using MFK1-B kappa bridge (AGICO) equipment with a manual holder and SAFYR software. Instrument calibration and empty holder correction were performed prior to the analysis. MS was recalculated considering the fresh sample weight and expressed in SI units (10^{-9} m^3/kg) (Blumentritt, Lascu 2015). All sediment cores were correlated in between based on the results of the MS measurements.

Loss-on-ignition Analysis

Loss-on-ignition (LOI) analysis was conducted on 36 samples using a high accuracy electric fibre-insulated chamber furnace SNOL 30/1300, following the routine LOI methodology (Dean 1974; Santisteban *et al.* 2004) in the laboratory of the Institute of Geosciences, Vilnius University. The samples were dried at a temperature of 105°C; then heated to 550°C to combust organic matter, and then to 900°C to eliminate carbonate matter. Each sample was weighed both before the analysis and after each heating stage. Measurements enabled the determination of the organic matter, carbonate matter and mineral matter as percentage of dry weight in each sample.

Radiocarbon Dating

Four bulk samples from the 10 cm thick sampler were taken for ^{14}C dating: 325–323 cm, 340–338 cm, 359–357 cm, and 375–373 cm (expectedly representing the age of samples covering a few centuries before the 8.2 ka event, the beginning of the event, the end of the event, and a few centuries after the event, respectively).

Conventional ^{14}C dating with the application of liquid scintillation counting (LSC) radiocarbon analysis was applied to identify the age of bulk sediment samples. The ^{14}C measurements were conducted in the Laboratory of Nuclear Geophysics and Radioecology at the Nature Research Centre in Vilnius, Lithuania.

Radiocarbon dates were calibrated using the OxCal v.4.4.4 program (Ramsey 2009) and the IntCal20 calibration curve (Reimer *et al.* 2020). All dates are reported with the confidence level of 1 (68.27%) and 2 (95.45%) and expressed in calibrated years before 1950 AD (cal yr BP).

Pollen Analysis

Sample preparation for pollen and spore analysis was carried out in a laboratory of the Nature Research Centre (Vilnius, Lithuania). In total, 38 pollen and spore samples of 2 cm^3 each were prepared following the procedure using HF and acetolysis (Berglund, Ralska-Jasiewiczowa 1986; Bennett, Willis 2001). A minimum of 500 terrestrial pollen grains were identified in each pollen sample. Pollen identification relied on Faegri and Iversen (1989) and Moore *et al.* (1991) identification keys and on PalDat (2024) – an online palynological database.

Pollen percentages were calculated based on the total pollen sum consisting of both arboreal pollen (AP) and non-arboreal pollen (NAP), excluding aquatic pollen. Percentages of aquatic pollen, spores and non-pollen palynomorphs (NPP) were calculated relative to the total pollen sum. In addition, sums of AP, NAP and *Quercetum mixtum* (QM) were calculated to facilitate pollen data interpretation. The results of pollen analysis are represented in a percentage pollen diagram, created using TILIA program (Grimm 2011). All pollen and spore taxa having < 1% maximum values were not included in the pollen diagram. Besides pollen and spores, charcoal (> 5μm) percentages were included in the pollen diagram. These percentages were calculated relative to the total pollen sum as well.

RESULTS

Chronology

The chronological classification of sediments was performed based on ^{14}C radioisotope dating of 4 sediment samples (Table 1). The construction of the age-depth model (Fig. 2) was performed using the Bayesian depositional model OxCal 4.4.4 (Ramsey 2009) with the OxCal P_Sequence model (Ramsey 2008).

Magnetic Susceptibility

The MS values at the bottom (376–372 cm depth) of the section presented in this paper are relatively stable, varying from -5.3524 × 10^{-9} m³/kg to -5.0741 × 10^{-9} m³/kg (Fig. 3). The MS forms a distinct peak, reaching up to -3.9614 × 10^{-9} m³/kg at the depth interval of 372–370 cm (representing approximately 8650–8600 cal yr BP). Further up, the MS values rebound to approximately -4.5 × 10^{-9} m³/kg and gradually decrease until the top of the sequence (338–337 cm depth, representing 7990 cal yr BP) to around -7 × 10^{-9} m³/kg.

Loss-on-Ignition

The content of organic matter (Fig. 3) follows a pattern similar to that of MS. At the bottom (372 cm depth and below) of the analyzed section, LOI550 values range from 55.8% to 58.2%. At the depths of 372–370 cm, LOI550 drops to 47.2%–48.9%. Further up, it increases steadily until the top of the sequence. Between 369–359 cm depths (8720–8410 cal yr BP), the increase is sharper (from approximately 52% to 68%), while in the interval of 358–337 cm (8380–7990 cal yr BP), the slope of the increase is less steep (from approximately 70% to 75%), though still clearly observable. The carbonate matter percentage varies between approximately 1.5% and 4%, showing a decreasing trend towards the top of the sequence.

Pollen data

Pollen assemblages in the investigated sequence are dominated by tree and shrub pollen (Fig. 3). AP values are relatively stable throughout the sequence, varying within 90.1–97.9%, and average being 95.2%. The lowest values are observed at the depths of 360–357 cm (8410–8380 cal yr BP).

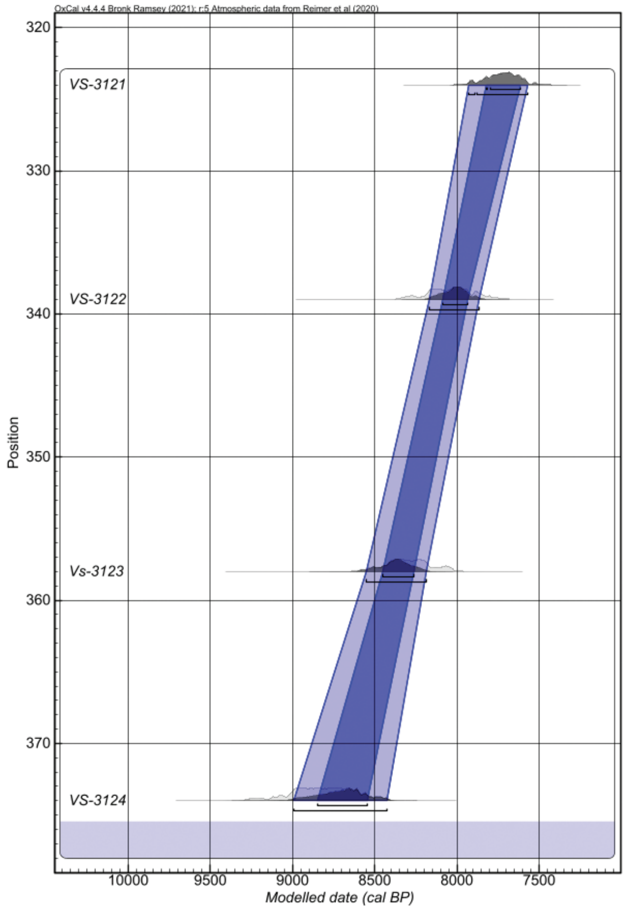

Fig. 2 Calibrated radiocarbon age versus depth model generated using OxCal software

Table 1 Results of ^{14}C measurements

No.	Laboratory code	Depth, cm	Uncalibrated ^{14}C years BP	Age, cal yr BP		Dated material
				1σ (68.3%)	2σ (95.4%)	
1	VS-3121	323–325	6870 ± 104	7830–7810 (4.2%) 7795–7610 (64.0%)	7935–7890 (5.5%) 7880–7565 (89.2%) 7530–7515 (0.8%)	TOC
2	VS-3122	338–340	7205 ± 136	8180–7925 (64.1%) 7895–7870 (4.2%)	8335–7775 (94.7%) 7770–7750 (0.7%)	TOC
3	VS-3123	357–359	7505 ± 144	8450–8170 (67.5%) 8070–8060 (0.8%)	8590–8560 (1.3%) 8555–8020 (94.1%)	TOC
4	VS-3124	373–375	7950 ± 143	8995–8635 (66.6%) 8620–8605 (1.7%)	9140–8425 BP (93.6%) 9260–9225 (1.0%) 9205–9175(0.9%)	TOC

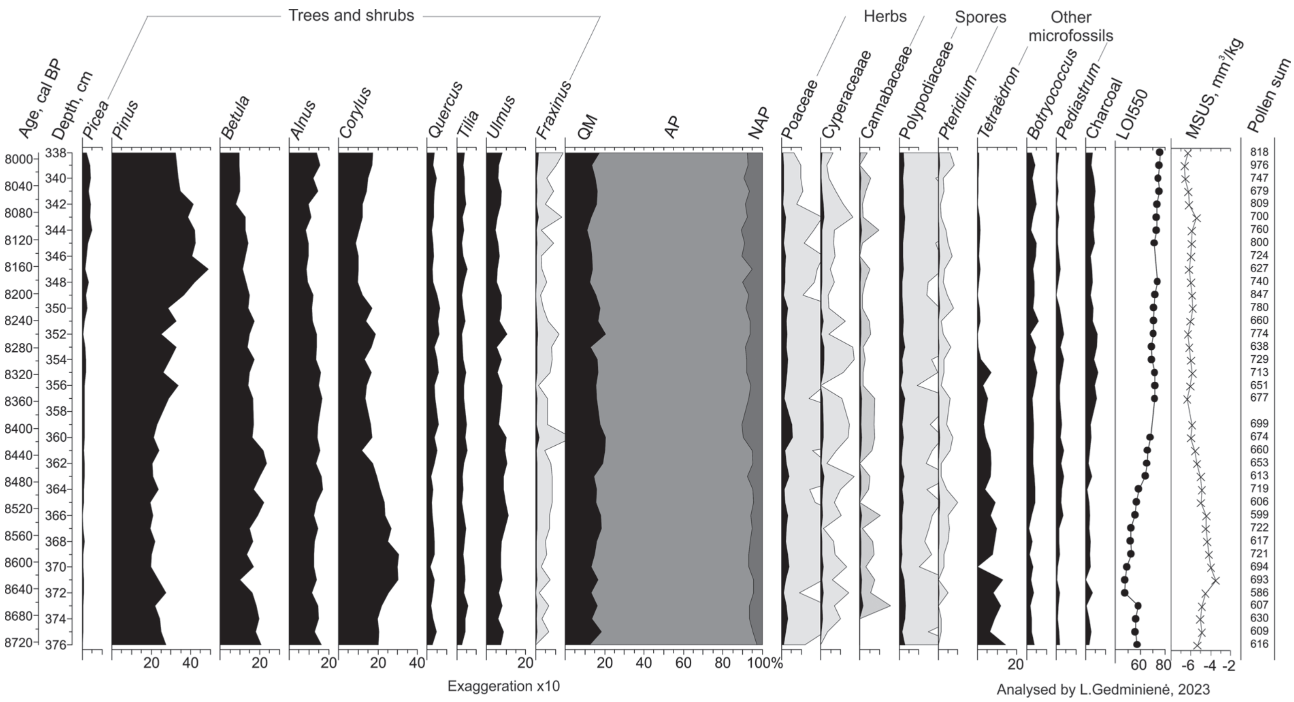

Fig. 3 Pollen diagram of the sediments of Lake Amalvas with LOI and MS values

The percentages of *Pinus* vary between 19.5% and 27.6% in the lower part of the sequence (358 cm and below, corresponding to 8720–8400 cal yr BP). At the depths of 358–349 cm (8400–8220 cal yr BP), *Pinus* percentages vary more and within a wider interval, 29.7–34.8%. In the top part of the sequence (8220–7990 cal yr BP), values are even higher – 33.9–49.4%. The percentage range of *Betula* is relatively narrow, varying between 8.5% and 23.5% and averaging 15.6%. The highest values of this taxon (16.9–23.5%) are observed at the depths of 360–366 cm (8530–8430 cal yr BP). Percentages at the bottom part of the sequence (372–376 cm; 8720–8670 cal yr BP) are relatively high as well (18–21%). The lowest *Betula* values (8.5–10.5%) are in the top part of the sequence (342–337 cm; 8070–7990 cal yr BP). The percentages of *Alnus* vary within the interval of 8.9–17.1%. The highest values (13.8–17.1%) of this taxon occur at the depths of 351–365 cm (8510–8260 cal yr BP), and the lowest (8.9–11.5%) at 348–341 cm depth (8180–8070 cal yr BP). *Corylus* is abundant in the lower part of the sequence (reaching 30.9% at 369 cm depth, which corresponds to 8590 cal yr BP). From this point upwards it starts to decrease, declining briefly to as low as 11.9% at 361 cm depth (8400 cal yr BP) and reaching the minimal value 9.4% at 345 cm (8130 cal yr BP), after which it gradually recovers to its average values. The amount of *Picea* pollen is below 1% at 364 cm (corresponding to 8490 cal yr BP) and below, although it gradually increases throughout the sequence, reaching as high as 2.2–5.2% at the depths of 346–337 cm (8140–7990 cal yr BP).

The percentages of *Quercetum mixtum* are varying between 11.8% and 20.9%. The highest percentages of *Quercetum mixtum* (19.2–20.9%) occur at the depths of 362–359 cm (8450–8410 cal yr BP) and 352 cm (8260 cal yr BP), and the lowest (11.8–14.2%) at the depths of 348–342 cm (8180–8090 cal yr BP). These intervals are influenced mostly by variations of *Ulmus*, the most abundant among *Quercetum mixtum* taxa, while *Quercus* and *Tilia* vary far less. The percentages of these two taxa mostly follow the same pattern, although *Quercus* is somewhat (by 1–2%) more abundant than *Tilia* at the depths of 355–348 cm (8320–8200 cal yr BP), while *Tilia* is more abundant at 374–369 cm (8690–8610 cal yr BP) by a similar amount; the percentage of *Fraxinus* makes up to 1.8%.

Only occasional *Salix* and *Juniperus* shrub pollen grains appear throughout the sediment core. *Salix* occurrences are somewhat more consistent at the bottom of the core where it makes up to 0.9%.

Herb percentages vary considerably from sample to sample, although the decreasing trend towards the top is noticeable. Herb pollen makes 4–6% at the bottom of the sequence, and 2–4% at the top. Exceptionally high herb values (up to 9.9%) are observed at 360–358 cm depth (8410–8400 cal yr BP). Herbs are predominantly represented by Poaceae (up to 5.4%), Cyperaceae (up to 1.7%), and Cannabaceae (up to 1.5%). The percentages of other herb taxa remain below 1%. Aquatic pollen is identified only sporadically throughout the analyzed sequence.

The percentages of *Tetraëdron* green algae fluctuate above 7% in most samples at the bottom of the analyzed sequence and sharply drops to below 2% at a depth of 353 cm. *Botryococcus*, on the other hand, demonstrates a sharp increase from 1.3% at a depth of 367 cm to 4.9% at a depth of 365 cm and remains at the same level up to the top of the sequence. The highest percentages (1.9–4.3%) of *Pediastrum* type green algae are observed at the depths of 366–349 cm (8530–8200 cal yr BP), while they are well below 2% in most samples outside this interval.

DISCUSSION

During the period of approximately 8720–8500 cal yr BP, the pollen assemblages in Lake Amalvas sediments reflect vegetation patterns typical of southern Lithuania at that time. The percentages of hazel (*Corylus*) pollen are comparable to those of pine (*Pinus*), which is characteristic of the Late Boreal, when hazel pollen reached its maximum values throughout the Holocene (Kabailienė 2006; Stančikaitė *et al.* 2019). It is worth noting that pine is one of the highest pollen-producing taxa, while hazel produces significantly less pollen and its production is several to more than 10 times lower (Wieczorek, Herzschuh 2020). Thus, hazel vegetation was likely more abundant than pine vegetation in the region. Although the relationship of AP/NAP ratio and the extent of forestation is not strictly linear (Favre *et al.* 2008), the extremely high AP values during the above-mentioned period indicate (Li *et al.* 2010) that the region was fully, or nearly-fully, overgrown with forest. Alder (*Alnus*) and deciduous tree (*Quercetum mixtum*) pollen percentages are fairly stable, suggesting that these taxa were well-established. The decline of birch (*Betula*) throughout the investigated sequence represents a part of its general decline after the maximum spread in the beginning of the Holocene (Kabailienė 2006; Stančikaitė *et al.* 2019) that took place ca. 10,000 cal yr BP (Druzhinina *et al.* 2020).

A sharp decrease in LOI550 and an increase in MS at 8650 cal yr BP both indicate disturbance in the landscape. No globally recorded climatic events are known at this time, nor have any similar contemporaneous changes been recorded in other Lithuanian cores (Stančikaitė *et al.* 2009, 2019; Druzhinina *et al.* 2020). Therefore, these changes rather represent local hydrological changes within the Lake Amalvas catchment area. Both curves gradually stabilize and reach their previous values by 8490 cal yr BP.

The hazel maximum is one of the most prominent features of the Early Holocene pollen diagrams throughout the region (Kabailienė 2006). The high-resolution and robust chronology of the Lake Amalvas pollen sequence, in addition to earlier Lake Amalvas pollen analysis results (Juodagalvis, Balakauskas, 2012), enables a precise dating of this event. Our data indicate that the hazel peak persisted from 8640 to 8590 cal yr BP. This information can be used as a chronological marker for future pollen investigations in the area. The hazel maximum in NE Poland (Fig. 4) is mostly recorded 9200–8800 cal yr BP (Ralska-Jasiewiczowa 1966; Wacnik 2009; Mirosław-Grabowska *et al.* 2015; Pędziszewska *et al.* 2015; Fiłoc *et al.* 2017). At some sites in NE Poland it was recorded as early as 9500 cal yr BP (Gałka *et al.* 2015) or as late as 6500 cal yr BP (Gałka *et al.* 2014), but these present outliers, possibly due to local vegetation specifics. In Latvia and N Lithuania, it is dated to 7900–7300 cal yr BP (Heikkilä, Seppä 2010; Stivrins *et al.* 2014; 2015; 2017; Stančikaitė *et al.* 2020). Hazel apparently spread in the NE direction at a rate of approximately 0.3–0.4 km/yr, and our data agree well with such timing. However, it is difficult to confirm this with the data from other Lithuanian sites. For instance, pollen records from Čepkeliai (Stančikaitė *et al.* 2019) and Briaunis (Gryguc *et al.* 2013) pollen sites cover this interval with relatively good resolution, suggesting the Early Holocene hazel maximum to be at around 8100 and 8900 cal yr BP, respectively. However, a gap of over 2500 years exists between the nearest dates surrounding the hazel maximum in both sites, and one of the two nearest dates in the Čepkeliai record comprises a reversal. Uneven sedimentation could significantly impact the dating error of this event. Given this and a poor alignment with other regional data, these results should be interpreted with caution.

An increase in birch pollen and, to a lesser extent, herb pollen during the period of 8530–8430 cal yr BP, along with a decrease in thermophilous tree pollen may indicate cooler conditions. Although such changes are typical of the 8.2 ka event (Tinner, Lotter 2001; Veski *et al.* 2004; Seppä *et al.* 2005; Kofler *et al.* 2005; Wehrli *et al.* 2007; Hede *et al.* 2010; Ghilardi, O'Connell 2013; Stivrins *et al.* 2014; Fiłoc *et al.* 2017), its onset is typically recorded around 8400 cal yr BP or later. An earlier cooling observed here might be related to a longer-term event on which the 8.2 ka event is often superimposed. Rohling and Pälike (2005) found that such event took place from approximately 8500 cal yr BP to 8000 cal yr BP. They also argue that the longer-term event is the most evident in summer-dominated proxies, while the sharper (8.2 ka) event is the most evident in winter-dominated proxies. Indeed, as most plants flower during the late spring and summer, their pollen could rather be considered a summer-dominated proxy. It should be noted that our ^{14}C dates were determined with the standard error of up to 150 yrs. In theory, these changes could fall somewhere among the earliest-recorded cases of the 8.2 ka event; however, this is not very likely taken the consistency of the age-depth model

Fig. 4 The timing (cal BP) of Corylus maximum in high-resolution, well-dated SE Baltic pollen diagrams. Numbers of sites (shown in brackets): 1 – Suminko (Pędziszewska *et al*. 2015); 2 – Gościąż (Ralska-Jasiewiczowa *et al*. 1998); 3 – Miłkowskie (Wacnik 2009); 4 – Romoty (Mirosław-Grabowska *et al*. 2015); 5 – Hańcza (Lauterbach *et al*. 2011); 6 – Linowek (Gałka *et al*. 2014); 7 – Kojle–Perty (Gałka *et al*. 2015); 8 – Suchar Wielki (Fiłoc *et al*. 2017); 9 – Suchar (Fiłoc *et al*. 2017); 10 – Čepkeliai (Stančikaitė *et al*. 2019); 11 – Briaunis (Gryguc *et al*. 2013); 12 – Petrešiūnai (Stančikaitė *et al*. 2020); 13 – Ķikuru (Stivrins *et al*. 2017); 14 – Lielais Svētiņu (Stivrins *et al*. 2014; 2015); 15 – Kurjanovas (Heikkilä, Seppä 2010)

and good agreement with earlier dating of the same sediments (Juodagalvis, Balakauskas 2012).

The period from 8510 to 8260 cal yr BP is marked by a notable increase in alder (*Alnus*) pollen, suggesting more humid conditions. The boundaries of this interval also coincide with sharp changes in algal composition, such as the increase of *Botryococcus* and *Pediastrum* around 8500 cal yr BP and the subsequent decline of *Tetraëdron* and *Pediastrum* at ~ 8200 cal yr BP. Interestingly, the evidence regarding alder pollen percentages and associated humidity levels during the 8500–8000 cal yr BP across the region is rather contradictory. While some studies report increased alder pollen values and wetter conditions (Paus *et al.* 2019; Stančikaitė *et al.* 2019), other studies report a decrease in alder pollen, suggesting drier conditions (Fiłoc *et al.* 2017). This discrepancy likely reflects the spatial variability of climate patterns during this time, with some areas experiencing wetter conditions while others underwent drying. Such regional heterogeneity could be explained by localized factors, such as varying landscape topography, proximity to water bodies, or the differential response of vegetation to climatic events. For instance, Lake Amalvas' catchment area may have been more sensitive to moisture changes, leading to the observed increase in alder pollen, while other sites may not have registered the same intensity of hydrological shifts. This variability emphasizes the importance of multi-site comparisons and high-resolution studies in interpreting paleoclimatic trends.

The absence of clear evidence of the 8.2 ka event at Lake Amalvas is noteworthy, especially given its recognition as a major climatic event in many other European records. Most of the pollen taxa percentages fluctuate within their normal range; no indicators of cooling are noted. Both the LOI and MS signals are more or less stable, in contrast to the expected LOI decrease typically associated with the 8.2 ka event (Nesje, Dahl 2001; Kurek *et al.* 2004; Paus *et al.* 2019). Many authors stress the importance of the decrease in thermophilous tree pollen production at this time (e.g., Veski *et al.* 2004; Heikkilä, Seppä 2010), yet no such decline is observed in Lake Amalvas sediments, which suggests that the 8.2 ka event might have been less impactful in this region. One explanation for the subdued response could be the site's geographic location. Rohling and Pälike (2005) argue that at most locations remote from the North Atlantic, the signals around the 8.2 ka event are less pronounced. Furthermore, studies in the Baltic region (Seppä *et al.* 2007) show that the cooling was more pronounced in the north, while temperature decrease was less prominent at 57–60°N (by approximately 1°C) compared to higher latitudes. As Lake Amalvas lies even further south, it may have experienced even milder cooling, which could explain the absence of clear climatic markers during this interval. On the other hand, evidence of the 8.2 ka event has been recorded in NE Poland, approximately 50 km SE from Lake Amalvas (Lauterbach *et al.* 2011; Gałka *et al.* 2014), which shows that it can still be noticeable at these latitudes, possibly due to the local conditions more sensitive to climate cooling. Some researchers (Gryguc *et al.* 2013; Stančikaitė *et al.* 2019) also noted a possible 8.2 ka event indication in Lithuanian pollen diagrams; however, these conclusions could be tentative due to low-resolution sampling. With only 1–2 samples covering the event's time span and uncertainties in the chronological framework, such data are insufficient for robust interpretations. This emphasizes the need for high-resolution datasets and more precise dating to accurately assess the impact of short-term climatic events like the 8.2 ka event in the region.

A sharp increase in pine pollen observed in Lake Amalvas sediments at 8200–8160 cal yr BP is a notable feature that aligns with similar findings in other pollen diagrams in S Lithuania. For instance, a similar pine peak is noticeable around 8100 cal yr BP in Lake Briaunis situated 80 km NE from the Amalvas site (Gryguc *et al.* 2013). Similarly, a pine peak is identified at 8000 cal yr BP in the Čepkeliai bog situated 50 km SE of Lake Amalvas (Stančikaitė *et al.* 2019). It should be noted, however, that the pine pollen peak is less prominent and not seen in many of more distant pollen sites, suggesting that regional variations may influence the visibility of this trend. In addition, as mentioned above, both Briaunis and Čepkeliai have less detail chronologies at this time interval and the exact timing of the pine peak in these locations is still to be determined by future investigations, preferably involving AMS dating. Nevertheless, it is possible that the pine peak will turn out to be traceable throughout S Lithuania. In this case, our date of the peak could serve as a chronological reference in future research in the region.

CONCLUSIONS

High-resolution analyses of Lake Amalvas sediments have revealed a regional environmental response during the 8720–7990 cal yr BP time interval. The pollen assemblages in these sediments predominantly reflect regional vegetation patterns due to the lake's size, with minimal influence from local vegetation, especially notable during the studied time interval when the lake was significantly larger than today.

An increase in magnetic susceptibility and a simultaneous decrease in organic matter values at 8650 cal yr BP suggest landscape instability caused by local hydrological changes rather than by global climatic events. These signals recovered and stabilized by 8490 cal yr BP. An increase in alder pollen percentages from 8510 to 8260 cal yr BP, alongside the changes in algae composition, suggests an increase in humidity during this period. However, evidence from nearby sites regarding this trend is mixed, highlighting the complexity of hydrological dynamics in the region.

A slight increase in birch pollen and decrease in thermophilous tree pollen between 8530 and 8430 cal yr BP indicate a cooling event, possibly a broader cooling trend observed elsewhere in Northern Europe that preceded the 8.2 ka event and associated with summer-dominated proxies. No clear evidence of the 8.2 ka event itself is found at Lake Amalvas. This suggests that the event had only a mild impact on southern Lithuania compared to more northern regions.

Our data enabled precise dating of the Early Holocene hazel maximum observed in the pollen sequence from 8640 to 8590 cal yr BP. It is consistent with other regional data and can serve as an important chronological marker for future studies in southern Lithuania. A sharp increase in pine pollen observed at 8200–8160 cal yr BP in Lake Amalvas aligns with similar, though less well-dated, events in other sites in southern Lithuania. This pine pollen peak could serve as an additional chronological reference point for future paleoenvironmental studies.

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