

HYDROLOGICAL AND ENVIRONMENTAL CHANGES OF THE LAST MILLENNIUM IN NW ROMANIA

Agnes RUSKAL^{1,2}, Andrei-Cosmin DIACONU², Andrei PANAIT² & Ioan TANȚĂU^{1,2*}

¹*Babeș-Bolyai University, Department of Geology, M. Kogălniceanu 1, 400084 Cluj-Napoca, Romania; agnes.ruskal@gmail.com, ioan.tantau@ubbcluj.ro*

²*Center for Integrated Geological Studies, M. Kogălniceanu 1, 400084 Cluj-Napoca, Romania; andreicosmind@yahoo.com, pnt_andrei@yahoo.com*

**Corresponding author: ioan.tantau@ubbcluj.ro*

Abstract: Climate, environmental, and hydrological changes are an increasing concern, as they affect both ecosystems and human well-being. By studying past changes, we can better understand the current impacts and consequences of current transformations and take informed action regarding the future. In this study, we analyzed a peat sequence from Tăul Fără Fund (Pădureni-Țop area – Transylvanian Basin) using abiotic methods (lithology, radiocarbon dating, loss on ignition, magnetic susceptibility) and biotic methods (testate amoebae, microscopic charcoal particles) to reconstruct the evolution of the peatland and the environmental and hydrological changes that occurred over the last millennium. We identified drier periods between AD 1000–1150, AD 1400–1650, and AD 1850–1950, and wetter periods between AD 900–1000, AD 1150–1400, AD 1650–1850, and from AD 1950 to the present. Comparing our results with other studies from Romania, we found that they are relatively consistent, with local conditions at Pădureni-Țop closely matching regional trends.

Keywords: testate amoebae, peatland, palaeoenvironment, palaeohydrology, last millennium

1. INTRODUCTION

Climate, environmental, and hydrological changes have become increasingly frequent in recent decades, significantly affecting ecosystems and human well-being. Most of these changes are the result of anthropogenic impact, while a smaller proportion results from natural factors (Bindoff et al., 2013). Water availability is a rising concern globally. In Europe, there is a growing trend of seasonal soil drying and an increase in drought events, which pose major challenges for agriculture, forestry, infrastructure, and natural ecosystems and habitats (Ruosteenoja et al., 2018). The Southern part of Europe, including Romania, is increasingly considered vulnerable to various types of droughts (meteorological, hydrological, and pedological) (IPCC, 2014). Given the high impact of such phenomena on the socio-economic sector, it is crucial to assess the magnitude and severity of future droughts (Ioniță et al., 2016).

To make such assessments and anticipate the consequences of climate and hydrological changes on

the environment, we must first understand current and past phenomena. In Romania, meteorological observations have only been recorded over the past century. Palaeoclimatic, palaeohydrological, and palaeoenvironmental conditions have been reconstructed for the Holocene from peat or lake sediment sequences and speleothems, using pollen (Feurdean, 2005; Geantă et al., 2014; Tanțău et al., 2014), testate amoebae (Feurdean et al., 2015; Diaconu et al., 2016, 2017, 2020; Ruskal et al., 2020), and isotopes (Tămaș et al., 2005; Cristea et al., 2014), but high-resolution studies for the last 1,000 years – when anthropogenic impact has been a constant factor – remain relatively scarce (Diaconu et al., 2020; Feurdean et al., 2015; Florescu et al., 2017).

In this study, we investigated a peat sequence from Tăul Fără Fund in northwestern Romania using abiotic (lithology, radiocarbon dating, loss-on-ignition (LOI), magnetic susceptibility (MS)) and biotic methods (testate amoebae (TA), microcharcoal particles (MC)) to reconstruct environmental and hydrological conditions over the past millennium.

The objectives of this study were to: 1. analyze the physical properties of the sediments to determine the phases of the peatland evolution; 2. analyze TA communities, their ecological preferences, and reconstruct the water table level; 3. identify the relationship between environmental conditions, natural processes such as landslides, fire and hydrological conditions; 4. determine the environmental response to Rapid Climate Change (RCC) events in Europe.

2. STUDY AREA

The studied site (Tăul Fără Fund) is located near the village of Pădureni-Țop, northeast of the town of Gherla, Cluj County, in the northwestern part of the Transylvanian Depression.

The peatland (47° 04' 52" N, 23° 59' 21" E; 420 m asl) (Figure 1) formed by landslides (Diaconeasa, 1985; Gârbacea et al., 2015) on an overlying basal marly clays and sandstones of Badenian age. It has an oval shape and covers an area of approximately 1 ha. The peat layer has an average thickness of 300 cm (Gârbacea et al., 2015).

The study site is surrounded by species of *Salix* and its surface is covered with *Betula verrucosa*, *Alnus glutinosa*, *Populus tremulus*, species of *Carex*, *Eriophorum*, *Parnasia* and *Sphagnum* (Diaconeasa, 1985).

3. MATERIALS AND METHODS

3.1. Sampling and chronology

A 335 cm long sequence was collected from Tăul Fără Fund with a Russian corer (6 cm diameter, 60 cm length). The cores were wrapped and transported to the laboratory, where they were cleaned, described through macroscopic lithological examination, and then subsampled.

The chronology was established by five ¹⁴C measurements performed at Isotopech Laboratory, Debrecen, Hungary. The radiocarbon ages were converted into calendar years BP using the Intcal20 database (Reimer et al., 2020) and transformed into AD (Anno Domini) years. The age-depth model was constructed with the smooth-spline method implemented by the Clam software (Blaauw, 2010).

3.2. Testate Amoebae

Testate amoebae data were used to reconstruct local hydrological conditions. TA are used as hydrological indicators because of their high sensitivity and immediate response to changes in soil

moisture or depth to water table levels (DWT) (Tolonen, 1992; Mitchell et al., 2008). We quantitatively reconstructed DWT levels using the transfer function developed by Amesbury et al. (2016), to identify wetter and drier periods in the peatland's history.

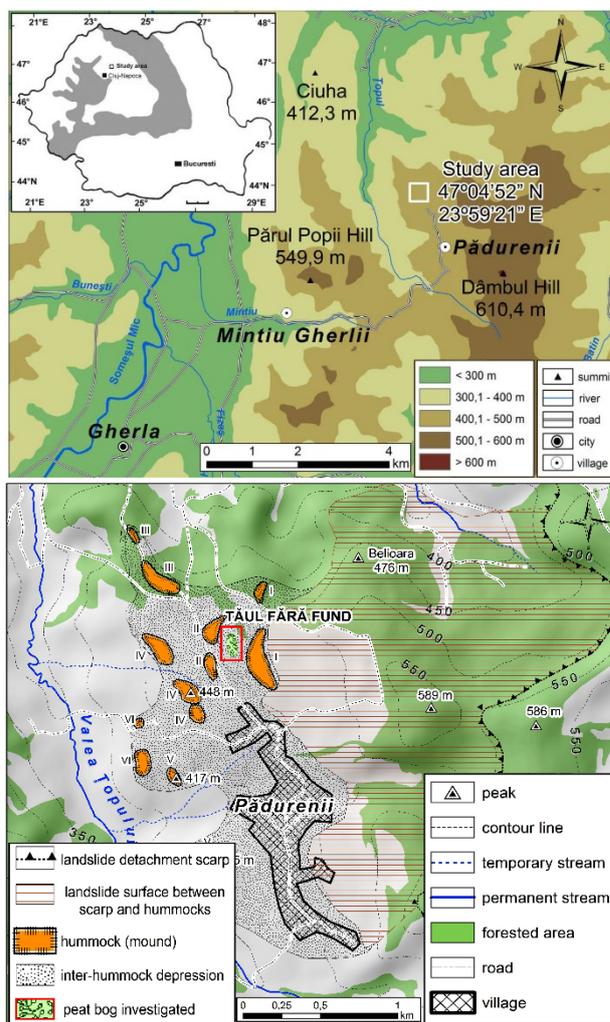


Figure 1. The study area and the geomorphological map of the region, after Gârbacea et al. (2015).

For the TA analysis, subsamples of 1 cm³ were collected at 8-16 cm resolution and prepared following the standard protocol (Charman et al., 2000). The samples were boiled for 10 min, stirred and then sieved through a 300- μ m mesh. The remains were centrifuged at 3000 rpm for 10 minutes and afterwards stored in glycerol. Each sample was analyzed under a microscope at 400X magnification, and a minimum of 150 specimens/sample were counted and identified. The testate amoebae zones (TAZs) were determined by a classical clustering analysis, using PAST software (Hammer et al., 2001). The DWT values were quantitatively reconstructed using the pan-European TA-based transfer function developed by Amesbury et al. (2016).

3.3. Peat physical properties

The physical properties of the sediments (determined through abiotic methods) provide insight into the formation and development of the peatland.

3.3.1. Loss on ignition (LOI)

The LOI method was used to determine the organic matter (OM), minerogenic matter (MM) and carbonates (CaCO₃) content and dry bulk density (DBD) of the samples (Heiri et al., 2001). The samples were dried at 105 °C for 12 hours, combusted at 550 °C for 4 hours and then at 950 °C for 2 hours, with weights recorded before and after each stage.

The amount of OM corresponds to the percentage of material lost after combustion at 550 °C, while the CaCO₃ content represents the percentage of mass lost after combustion at 950 °C. The amount of material remaining after combustion at 550 °C (MM) represents the minerogenic sediment transported into the depositional basin (Chambers et al., 2010).

Dry bulk density (BD) was calculated by dividing the dry mass of the sample (g) by the volume of the fresh sample (cm³) (Chambers et al., 2010).

3.3.2. Magnetic susceptibility

To determine the variation of ferromagnetic minerals along the profile, we measured the magnetic susceptibility (MS) at 1 cm resolution using a Bartington MS3 system with MS2E sensor.

MS is expressed in SI units, and due to the very low values obtained, they were multiplied by 10,000 for improved visualization.

3.4. Microcharcoal

To reconstruct the regional fire history, (Whitlock & Larsen, 2001), we analyzed the microscopic charcoal (MC) remains in the TA samples. In order to determine the concentration of microcharcoal (particles/cm³), we added *Lycopodium clavatum* (*Ly*) spores to the samples and counted at least 200 elements (sum of *Lycopodium* and microcharcoal) (Finsinger & Tinner, 2006). The concentration was calculated using the following formula: To obtain a clearer image of fire regime changes over time, the MC values were divided by the accumulation rate (cm/year) of each sample (Finsinger & Tinner, 2006).

$$MC = \frac{\text{no. of } Ly \text{ added} \times \text{no. of MC counted}}{\text{no. of } Ly \text{ counted}}$$

The visualization of the peat physical properties (Figure 3), TA assemblages and DWT

reconstruction (Figure 4) and the numerical data used for discussion of the results (Figure 5) was carried out using C2 software (Juggins, 2007).

4. RESULTS

4.1. Chronology and Lithology

Five samples were radiocarbon dated to establish the chronology of the studied sequence. The results obtained (both uncalibrated and calibrated) are presented in Table 1. The age-depth model (Figure 2) illustrates the accumulation rate (accrate) of peat material, which ranges from 0.026 to 0.233 cm/year.

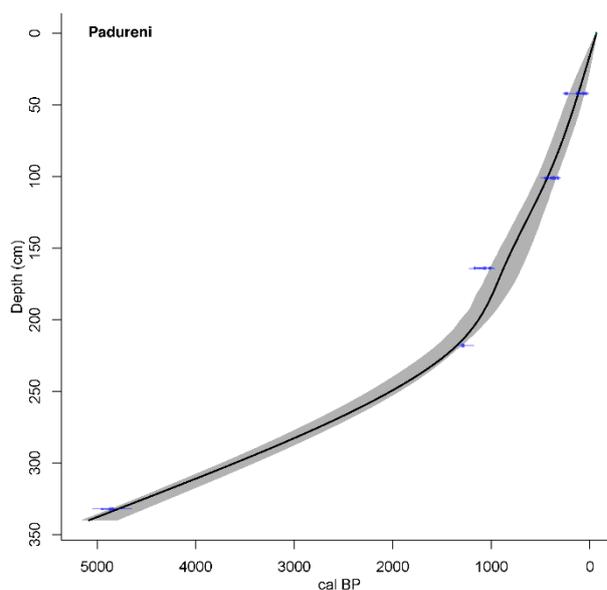


Figure 2. Calibrated AMS radiocarbon dates with dating error bars, and the age–depth model for the Tăul Fără Fund sequence. Data points used for the construction of the age–depth model are marked in blue.

Table 1. Results of the radiocarbon dating.

No.	Depth (cm)	Material	Age ¹⁴ C (yr BP)	Calibrated age (cal AD/BC)
DeA-15655	42	<i>Sphagnum</i>	94±15	cal AD 1812 - 1918
DeA-15657	101	<i>Sphagnum</i>	334±14	cal AD 1487 - 1635
DeA-15658	164	<i>Sphagnum</i>	1161±16	cal AD 776 - 949
DeA-15659	218	<i>Sphagnum</i>	1358±16	cal AD 648 - 674
DeA-15624	332	bulk	4298±31	cal BC 3011 - 2880

The simplified lithology of the profile is presented in Table 2. The base of the 335 cm-long profile consists of yellowish clay (335 - 290 cm) and clayey peat (290 - 270 cm). The next 150 cm of the profile is composed of brown peat with varying

degrees of decomposition, humification, and moisture content.

Table 2. Simplified lithological description.

Depth (cm)	Description
0-120	Fibrous peat, low degree of decomposition, color ranging from brown to reddish-brown, high moisture content
270-120	Decomposed peat, slightly fibrous, brown color, lower moisture content
270-290	Clayey peat, medium moisture content
290-335	Yellowish clay

The upper part of the profile consists of light brown, undecomposed *Sphagnum* peat. Here, we focus only on the last 1,000 years (the upper 190 cm).

4.2. Peat physical properties

Throughout the studied sequence (the upper 190 cm of the core collected from Tăul Fără Fund), the organic matter (OM) content fluctuated between 51% and 96% (Figure 3). The lowest values were recorded at the base of the sequence (between 190 - 163 cm and 143 - 131 cm), ranging from 51% to 78%. Between 163 and 143 cm, the values are slightly higher (71 - 85%), and after 131 cm, they begin to increase. Between 121 and 61 cm, the values consistently remain above 85%. At 59 cm, OM content drops abruptly to 61%, but then begins to return to previous levels, fluctuating between 76% and 90% from 57 to 21 cm. In the uppermost part of the profile (18 - 0 cm), OM values fluctuated slightly, ranging between 61% and 77%.

The minerogenic matter (MM) values represent the difference between the total sample volume (100%) and the OM percentage; thus, the lines on the graph are mirrored (Figure 3).

In the basal part of the profile, dry bulk density (DBD) values are directly proportional to MM values (Figure 3). Overall, high values are recorded between 190 and 123 cm, consistently above 0.1 g/cm³. The highest values were recorded at 173 cm (0.21 g/cm³) and 133 cm (0.19 g/cm³). Between 123 and 14 cm, DBD remained below 0.1 g/cm³. Toward the top of the sequence, the trend rose again, and in the last 14 cm, values rise above 0.1 g/cm³.

CaCO₃ values vary from 0 to 2.2% (Figure 3). In the first 30 cm of the sequence (190 - 161 cm), the general trend is slightly decreasing, from 1.4% to 0.7%. Between 161 and 133 cm, the trend reverses and becomes increasing, with CaCO₃ percentages reaching 2.1 - 2.2%. This is followed by a new decline between 133 and 95 cm, where values drop to 0%. In the upper part of the profile, values begin to rise

again, reaching 1.8%.

Magnetic susceptibility (MS) values fluctuate between -0.19 and 0.01 SI x 10,000 throughout the studied sequence (Figure 3). The highest values were recorded in the first 9 cm (190 - 183 cm), which includes the only positive values in the sequence. From 190 to 106 cm, the general trend is decreasing, with the lowest value (-0.19 SI x 10,000) recorded at 106 cm. From 106 cm to the top of the profile, the trend increases slightly, with minor fluctuations. Between 64 and 56 cm, the measurements showed large errors and were therefore excluded from the results.

The peat accumulation rate (Figure 3) remained relatively constant, with a slightly increasing trend: from ~0.12 cm/year at 190 cm to 0.23 cm/year in the uppermost part (18 - 0 cm).

4.3. Testate Amoebae Assemblages and Water Table Reconstruction

We analyzed the testate amoebae (TA) assemblages in 26 samples from Tăul Fără Fund and identified a total of 29 species (Figure 4). Among these, the most frequent species were *Cryptodiffugia sacculus*, *Cryptodiffugia oviformis*, and *Diffflugia pulex*, while *Archerella flavum* and *Assulina muscorum* were also frequently present. Using cluster analysis and species relative abundances in the PAST software (Hammer et al., 2001), we identified five testate amoebae zones (TAZ). The water table depth (DWT) values in the peatland fluctuated between 16 and 26.2 cm.

TAZ-1 (192 - 150 cm; AD 890 - 1150)

The most abundant species in this zone is *Cryptodiffugia oviformis*, with a frequency of 42% at the beginning, increasing to 64%, then decreasing to 45%, and rising again to 55%. Other abundant species include *Cryptodiffugia sacculus* (3 - 13%) and *Diffflugia pulex* (10 - 31%). *Arcella discoides* and *Centropyxis aculeata* are present with frequencies up to 8%, both showing a decreasing trend. *Archerella flavum*, *Centropyxis platystoma*, *Cyclopyxis arcelloides*, *Diffflugia pristis*, and *Phryganella acropodia* occur with frequencies up to 7%. During this period, DWT values show an increasing trend, from 16 to 25.6 cm.

TAZ-2 (150 - 120 cm; AD 1150 - 1385)

This zone is marked by a decline in the frequency of *Cryptodiffugia oviformis* (from 55% to 12%) and *Diffflugia pulex* (from 24% to 4%, then increasing again to 26%), and by an increase in *Cryptodiffugia sacculus* (from 13% to 36%, followed by a decline to 22%). Other significant species include *Archerella flavum*, which peaks abruptly around AD 1300 (up to 14%), as well as *Centropyxis aerophila*, *Centropyxis aculeata*,

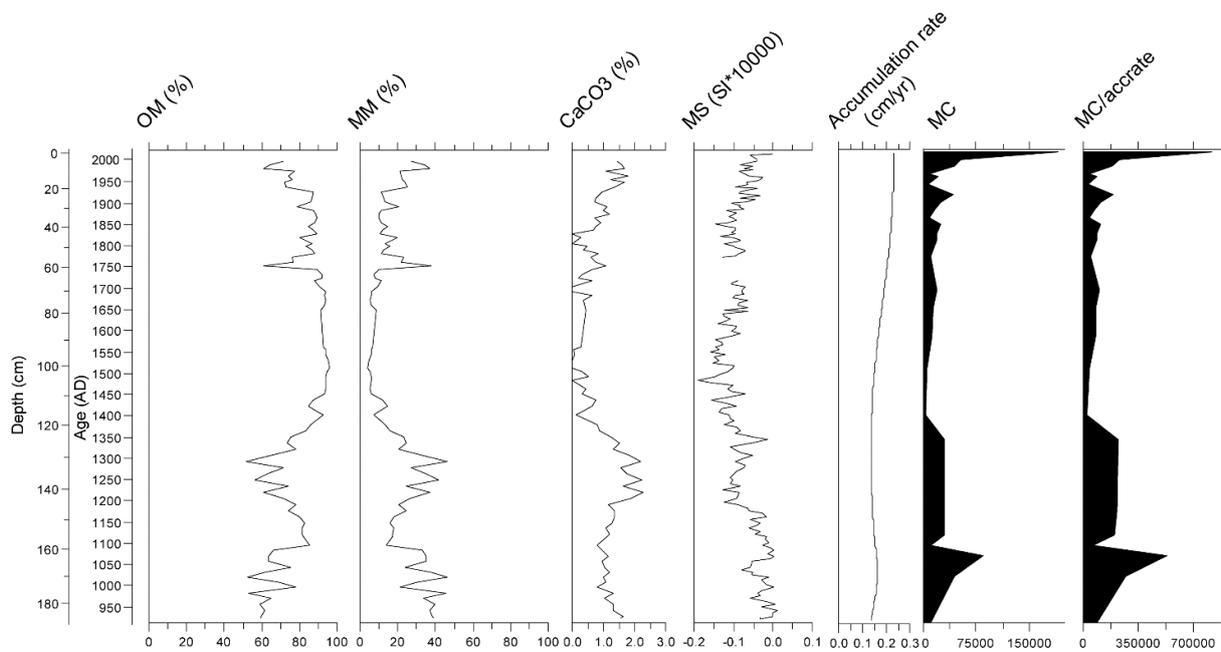


Figure 3. Physical properties: organic matter (OM), minerogenic matter (MM), CaCO₃, magnetic susceptibility (MS), and accumulation rate (cm/yr); microcharcoal frequency (MC) and MC divided by the accumulation rate.

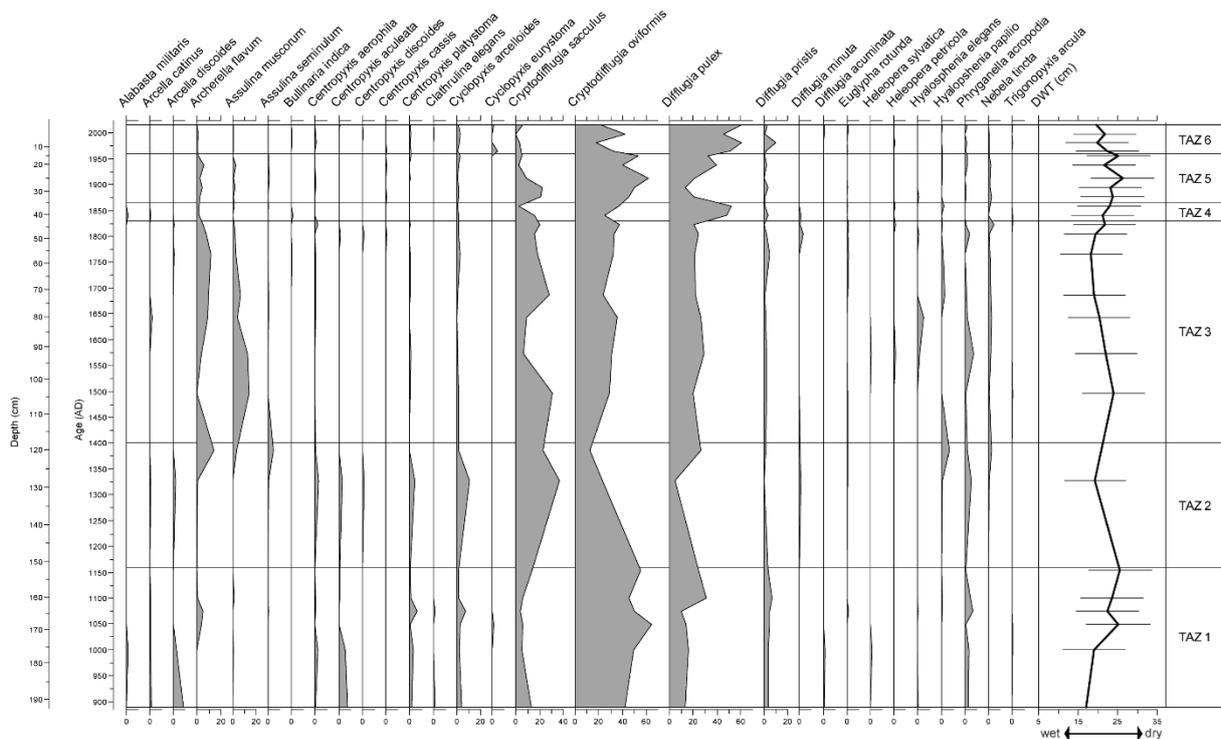


Figure 4. Testate amoebae relative abundance, depth to water table (DWT) and testate amoebae zone (TAZ).

Centropyxis platystoma, *Cyclopyxis arcelloides*, *Diffugia pristis*, *Hyalosphenia papilio*, *Nebela tinctoria*, and *Trigonopyxis arcuata*, with frequencies up to 10%. The DWT curve shows a generally decreasing trend from 25.6 cm to 16 cm.

TAZ-3 (120 - 44 cm; AD 1385 - 1822)

In this zone, *Cryptodiffugia sacculus* (6 - 30.5%), *Cryptodiffugia oviformis* (12 - 35.7%), and *Diffugia pulex* (19 - 29%) remain dominant.

However, *Archerella flavum* and *Assulina muscorum* also appear with significant frequencies (up to 14%). Other species such as *Centropyxis platystoma*, *Cyclopyxis arcelloides*, *Diffugia pristis*, *Euglypha rotunda*, *Hyalosphenia papilio*, *Phryganella acropodia*, and *Nebela tinctoria* are present with lower but relatively constant values. DWT values show an increasing trend in the first part of the zone (from 16 cm to 24 cm), followed by a decrease to 18 cm, and

then a slight upward trend towards the end of the zone.

TAZ-4 (44 - 32 cm; AD 1822 - 1877)

This is the shortest zone of the sequence from Tăul Fără Fund and is characterized by the dominance of *Diffflugia pulex* (47 - 52%). *Cryptodiffflugia oviformis* has a frequency of 24 - 36%, while *Cryptodiffflugia sacculus* shows a sharp decline to just 2.3%. Other species such as *Archerella flavum*, *Diffflugia pristis*, *Diffflugia minuta*, *Hyalosphenia papilio*, and *Nebela tincta* occur with frequencies up to 3.5%. DWT values show a slight increasing trend, rising from 19.4 cm to 23 cm.

TAZ-5 (32 - 16 cm; AD 1877 - 1955)

This zone shows a major increase in *Cryptodiffflugia oviformis*, which reaches up to 62%, then decreases slightly to 53%. *Diffflugia pulex* shows a relatively constant increasing trend, reaching 32.5% in the final part of the zone (and the sequence). *Cryptodiffflugia sacculus* continues its decreasing trend, from 21% to 5%. Other present species include *Archerella flavum*, *Assulina muscorum*, *Cyclopyxis arcelloides*, *Diffflugia pristis*, *Phryganella acropodia*, and *Nebela tincta*. During this zone, the water table depth fluctuates between 21 and 26.2 cm, with the highest value of the sequence (26.2 cm) recorded here.

TAZ-6 (16 - 0 cm; post-1955)

The final zone is characterized by the dominance of *Diffflugia pulex* (45 - 60%). The frequency of *Cryptodiffflugia oviformis* fluctuates between 17.8% and 42.4%, while *Cryptodiffflugia sacculus* remains low (0 - 6%). *Diffflugia pristis* shows an increase up to 10%. Other taxa – *Archerella flavum*, *Assulina muscorum*, *Bullinaria indica*, *Centropyxis aculeata*, *Centropyxis platystoma*, *Clathrulina elegans*, *Cyclopyxis arcelloides*, *Cyclopyxis eurytoma*, *Euglypha rotunda*, *Hyalosphenia papilio*, *Phryganella acropodia*, and *Trigonopyxis arcula* – are present in low proportions (1 - 4.5%). DWT values show a slightly decreasing trend, from 22.3 cm to 19.6 cm.

4.4. Microcharcoal

MC values fluctuated between 3222 and 191939 particles/sample (Figure 3). In the basal part of the sequence (190 - 128 cm), the frequency of charcoal fragments increases from 10,927 to 30,609, followed by a sharp decrease to 3222. Between 120 and 40 cm, MC values increase again, reaching up to 24,928, with a minor drop at 56 cm, where the value decreases to 10,666. At 36 cm, MC values decline further to 9,666. From this point to the top of the sequence, the overall trend is upward, with some

minor fluctuations, such as 20 cm (7,876) and 12 cm (9666). The highest MC value is recorded at the top of the sequence (0 cm), reaching 191,939.

The second MC curve in (Figure 3) was obtained by dividing the microscopic charcoal values by the peat accumulation rate. Since the accumulation rate remained relatively constant throughout the profile, the trends of both the MC and MC/accumulation rate curves are similar and directly proportional.

5. DISCUSSION

5.1. Evolution of the Tăul Fără Fund Peatland

Tăul Fără Fund formed as a result of landslides (known locally as *glimee*) in the Pădureni-Țop area. The peatland is not ombrotrophic, but minerotrophic. Although it is isolated from permanent or seasonal fluvial systems, it still receives minerogenic input and is affected by erosional processes caused by runoff events (Garbacea et al., 2015). Thus, the minerogenic material present in the peatland may have originated from eolian transport or surface runoff from the surrounding slopes. As a result, the water table level in this peatland is not solely controlled by precipitation and evapotranspiration – as in ombrotrophic peatlands (Charman et al., 2009) – but also by surface water input from adjacent slopes. Therefore, DWT in this context cannot be treated as a fully quantitative proxy for paleohydroclimate. Rather, it should be interpreted as a semi-quantitative variable, considering that runoff itself typically occurs during wetter periods with higher precipitation. Over the last 1000 years, peat accumulation has been relatively continuous (Figure 3) with no identified hiatuses or significant clay layers.

5.2. Reconstruction of Hydrological Fluctuations in the Pădureni-Țop Area and Regional Comparisons

The reconstructed values of DWT, OM/MM, CaCO₃, MC, and MS (Figure 5) indicate a series of environmental and hydrological changes within the peatland. Based on these variations, as well as on recognized climatic periods in both Europe and Romania, we have identified four major and distinct phases in the evolution of the Tăul Fără Fund peatland and its surroundings: the Medieval Climate Anomaly (MCA), the Transition Period (TP), the Little Ice Age (LIA), and the Contemporary Warm Period (CW). Additionally, we identified rapid climate change events (RCC) that had regional impacts.

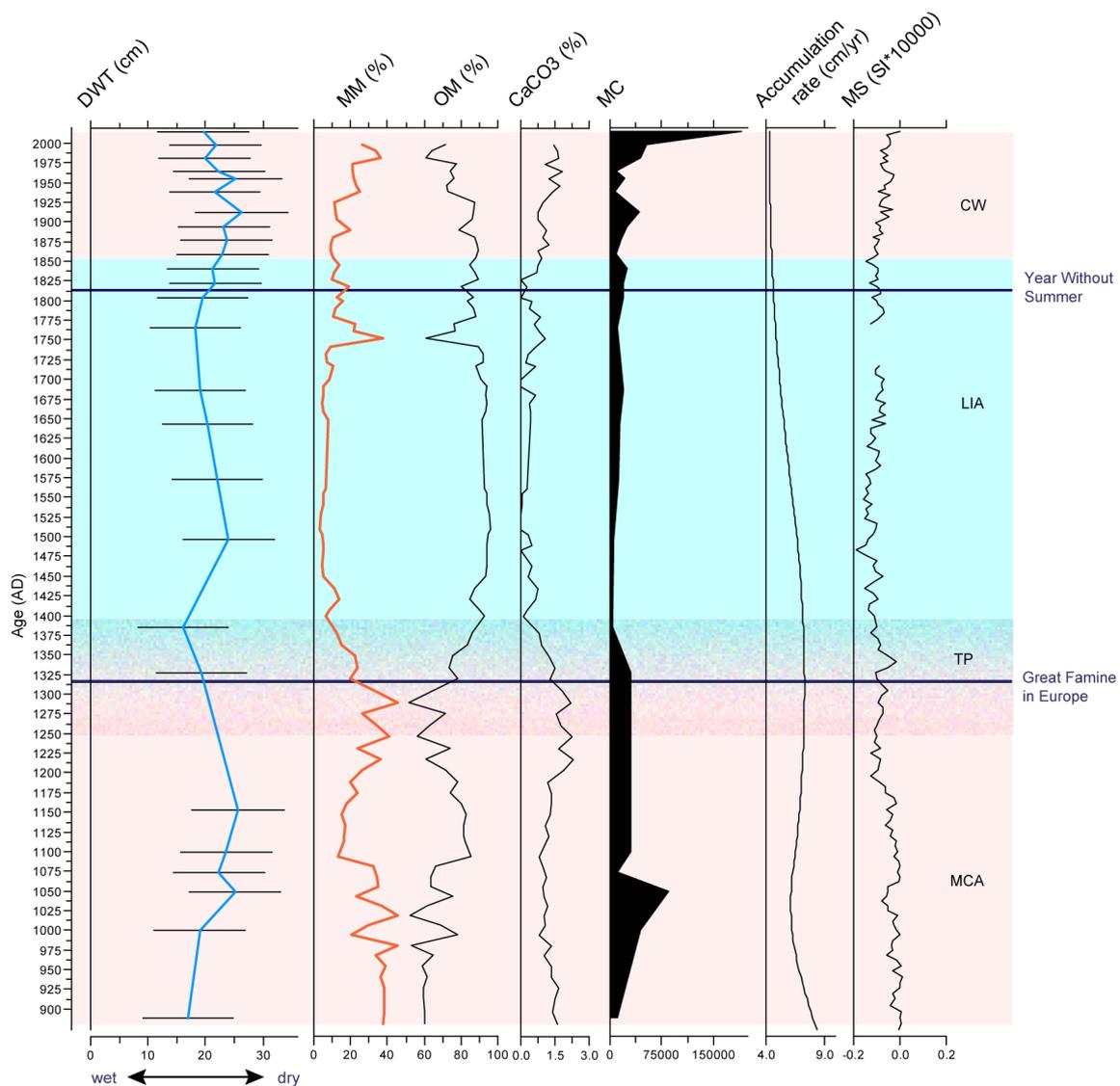


Figure 5. Correlation of the inferred variables from the Tăul Fără Fund sequence: depth to water table (DWT), minerogenic matter (MM), organic matter (OM), CaCO₃, microcharcoal frequency (MC), accumulation rate (cm/yr) and magnetic susceptibility (MS); peatland evolution phases: Medieval Climate Anomaly (MCA), the Transition Period (TP), the Little Ice Age (LIA), and the Contemporary Warm Period (CW) and identified rapid climate change events (RCC): Great Famine in Europe, Year Without Summer.

5.2.1. AD 900 - 1250 (Medieval Climate Anomaly – MCA)

During the first part of this phase, DWT values increased from 16.9 to 25.6 cm (Figure 5), indicating drier conditions in the peatland. The OM/MM curve shows an upward trend, with OM percentages ranging from 52% to 60% at the base of the sequence, increasing to 85% around AD 1100. This suggests that local conditions were favorable for peat accumulation. Between AD 900 and 1100, MC values increased, reflecting a higher frequency of vegetation fires. These fires may have been of anthropogenic or natural origin, but in either case, the dry conditions (also indicated by TA assemblages) would have facilitated fire activity. MS values were also highest during this period, pointing to enhanced input of ferromagnetic minerals

via aeolian transport or surface runoff.

In the same time interval, a peatland in the Rodna Mountains (NW Romania) recorded wetter conditions and lower DWT values, but high macrocharcoal concentrations (Feurdean et al., 2015). Regarding the high MM content, Panait et al. (2019) and Longman et al. (2017) also reported increased aeolian sediment input at Tăul Muced (Rodna Mountains) and Tinovul Mohoș (Eastern Carpathians).

Between AD 1100 and 1250, DWT values gradually decreased to 19 cm (Figure 5), suggesting wetter conditions. This decline in DWT was accompanied by an increase in minerogenic matter and CaCO₃ content, possibly sourced from the nearby Badenian sediments (marl and marly clays). MS values also decreased. Similar trends in DWT were

observed at Tăul Muced (Feurdean et al., 2015), while reconstructions from Tinovul Mohoș indicated stable but still wet conditions (Diaconu et al., 2020).

5.2.2. AD 1250 - 1400 (Transition Period – TP)

In the Northern Hemisphere, Mann et al. (2009) indicated the end of MCA at roughly AD 1250, and the beginning of LIA at around AD 1400. Between these, during a phase known as the Transition Period, the peatland water table rose by 3.2 cm, as DWT values dropped from 19.2 to 16 cm (Figure 5), marking the wettest phase of the sequence (around AD 1400). OM values increased and reached around 90%. Minerogenic input decreased: both MM and CaCO₃ content, as well as MS values, declined early in this period. MC concentrations were low during this phase, indicating a lack of significant fire activity in the area.

Between AD 1315 and 1322, the Great Famine struck Europe, including present-day Romania (Jordan, 1996). This climatic event was characterized by increased precipitation combined with low temperatures, which severely affected agriculture. This increased moisture is reflected in the DWT trend at Tăul Fără Fund (Figure 5) along with a concurrent rise in OM content.

5.2.3. AD 1400 - 1850 (Little Ice Age – LIA)

In the beginning of the LIA, DWT values increased again to 24 cm, indicating a return to drier conditions. Afterwards, DWT values show a gentle, uninterrupted downward trend from 22 to 18.3 cm (Figure 5) indicating increasingly wetter conditions in the peatland. In the final 50 years of this interval, DWT values began to rise again.

In the early part of this period (AD 1400 - 1730), OM values were consistently high (>90%), suggesting favorable conditions for plant growth and peat accumulation, with minimal external minerogenic input. This implies limited aeolian activity and surface runoff from adjacent slopes, though the continued presence of CaCO₃ indicates that runoff did occur occasionally. MC concentrations were low during this interval, consistent with the absence of major fires.

Similar hydrological fluctuations (a wet phase followed by drying) were recorded at both Tăul Muced (Feurdean et al., 2015) and Tinovul Mohoș (Diaconu et al., 2020). At Tăul Muced, MC values remained low, as observed at Tăul Fără Fund, while in the Eastern Carpathians, Diaconu et al. (2020) documented a sharp increase in both microscopic and macroscopic charcoal particles.

Between AD 1730 and 1850, small fluctuations appeared in OM, MM, CaCO₃, and MS. Around AD 1750, OM content dropped significantly (to 61%), while MM and CaCO₃ content rose, possibly indicating a notable runoff event. Following this event,

DWT values increased, suggesting a drying phase. MC concentrations also rose gradually.

At Tinovul Mohoș, DWT trends during the LIA were similar (Diaconu et al., 2020). However, at Tăul Muced, drier conditions characterized the early LIA, accompanied by increased fire activity, while wetter conditions dominated the latter part (Feurdean et al., 2015). Minerogenic input via aeolian dust was generally low at both sites (Panait et al., 2019; Longman et al., 2017).

Another important climatic event was the Year Without a Summer, triggered by the eruption of Mount Tambora in 1815, which led to widespread temperature and precipitation anomalies across Europe (Luterbacher & Pfister, 2015). At Tăul Fără Fund, this event corresponds with a rise in DWT (drying), MM, CaCO₃, and MS values.

5.2.4. AD 1850 - Present (Contemporary Warm Period)

The final section of the studied sequence captures fluctuations in the water table and physical properties of the peatland from AD 1850 to the present. DWT values generally increased between 1850 and 1900, indicating drier conditions during this century. Subsequently, DWT values declined (from 25.1 to 19.6 cm), reflecting a shift toward slightly wetter, though still dry, conditions.

Throughout this period, OM values showed a general downward trend with some fluctuations, while MM and CaCO₃ contents increased. MS values also trended slightly upward, pointing to an increase in ferromagnetic mineral input. MC concentrations show two significant peaks, around AD 1955 and 2015 suggesting increased fire activity during these times that may be correlated with the human activity of the surrounding localities.

Studies based on testate amoebae in the Eastern Carpathians and Rodna Mountains have identified wetter phases in the early part of this interval, followed by drier phases later (Feurdean et al., 2015; Diaconu et al., 2020). In the past 200 years, dust fluxes in NW Romania have also increased (Panait et al., 2019) indicating a change in the factors that control dust generation and transport (more arid surface conditions or human activity).

6. CONCLUSIONS

Through this study, which is one of the few high-resolution multi-proxy reconstructions from NW Romania, we reconstructed in detail the development of the Tăul Fără Fund peatland by analyzing the physical properties of the sequence and the hydrological changes inferred from testate

amoebae assemblages over the past 1000 years.

We identified phases when the water table was low (indicative of drier conditions), specifically during the intervals AD 1000 - 1150, AD 1400 - 1650, and AD 1850 - 1950. Periods of slightly higher water tables, reflecting wetter but still relatively dry conditions, were recorded between AD 900 - 1000, AD 1150 - 1400, AD 1650 - 1850, and from AD 1950 to the present.

We also inferred potential links between water table fluctuations, wet/dry periods, and natural processes such as landslides, wind-blown sediment input, surface runoff, and the subsequent deposition of these materials in the peatland.

Increased frequency or intensity of fire activity was recorded during the intervals AD 1000 - 1100, AD 1150 - 1350, AD 1850 - 1950, and from AD 2000 to the present.

We attempted to correlate our results with other paleoenvironmental and paleohydrological studies from Romania covering the last millennium. The similarities observed suggest that the local environmental conditions in the Pădureni-Țop area were largely consistent with regional-scale trends.

Finally, we examined how the Tăul Fără Fund peatland responded to rapid climate change events in Europe, such as the Medieval Climate Anomaly (MCA), the Transitional Period (TP), the Little Ice Age (LIA), the Contemporary Warming (CW), the Great Famine and the Year Without a Summer.

REFERENCES

- Amesbury, M.J., Swindles, G.T., Bobrov, A., Charman, D.J., Holden, J., Lamentowicz, M., Mallon, G., Mazei, Y., Mitchell, E.A.D., Payne, R.J., Roland, T.P., Turner, T.E. & Warner, B.G., 2016. *Development of a new pan-European testate amoeba transfer function for reconstructing peatland palaeohydrology*. *Quat. Sci. Rev.*, 152, 132-151, <http://dx.doi.org/10.1016/j.quascirev.2016.09.024>.
- Bindoff, N.L., Stott, P.A., AchutaRao, K.M., Allen, M.R., Gillett, N., Gutzler, D., Hansingo, K., Hegerl, G., Hu, Y., Jain, S., Mokhov, I.I., Overland, J., Perlwitz, J., Sebbari, R. & Zhang, X., 2013. *Detection and attribution of climate change: From global to regional*. In: Stocker, T.F., Qin, D., Plattner, G.K. et al. (eds) - *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge and New York, Cambridge University Press, 867-952.
- Blaauw, M., 2010. *Methods and code for 'classical' age-modelling of radiocarbon sequences*. *Quat. Geochron.*, 5, 512-518, <https://doi.org/10.1016/j.quageo.2010.01.002>.
- Chambers, F.M., Beilman, D.W. & Yu, Z., 2010. *Methods for determining peat humification and for quantifying peat bulk density, organic matter and carbon content for palaeostudies of climate and peatland carbon dynamics*. *Mires and Peat*, 7, 1-10.
- Charman, D.J., Hendon, D. & Woodland, W.A., 2000. *The Identification of Testate Amoebae (Protozoa: Rhizopoda) in Peats*. Technical Guide No. 9. Quat. Res. Assoc., London.
- Charman, D.J., Barber, K.E., Blaauw, M., Langdon, P.G., Mauquoy, D., Daley, T.J., Hughes, P.D.M. & Karofeld, E., 2009. *Climate drivers for peatland palaeoclimate records*. *Quat. Sci. Rev.* 28, 1811-1819, <https://doi.org/10.1016/j.quascirev.2009.05.013>.
- Cristea, G., Cuna, S.M., Fărcaș, S., Tanțău, I., Dordai, E. & Măgdaș, D.A., 2014. *Carbon isotope composition as indicator for climatic changes during the middle and late Holocene in a peat bog from Maramureș Mountains (Romania)*. *The Holocene*, 24, 15-23, <https://doi.org/10.1177/0959683613512166>.
- Diaconeasa, B., 1985. *Analiza palinologică a profilului turbos de la Pădureni-Țop, Jud. Cluj*. *Contribuții Botanice*, 71 - 76.
- Diaconu, A.C., Grindean, R., Panait, A. & Tanțău, I., 2016. *Late Holocene palaeohydrological changes in a Sphagnum peat bog from NW Romania based on testate amoebae*. *Studia UBB Geologia*, 60(1), 21-28, <http://dx.doi.org/10.5038/1937-8602.60.1.1285>.
- Diaconu, A.C., Tóth, M., Lamentowicz, M., Heiri, O., Kuske, E., Tanțău, I., Panait, A.M., Braun, M. & Feurdean, A., 2017. *How warm? How wet? Hydroclimate reconstruction of the past 7500 years in northern Carpathians, Romania*. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 482, 1-16, <https://doi.org/10.1016/j.palaeo.2017.05.007>.
- Diaconu, A.C., Tanțău, I., Knorr, K.-H., Borken, W., Feurdean, A., Panait, A. & Galka, M., 2020. *A multi-proxy analysis of hydroclimate trends in an ombrotrophic bog over the last millennium in the Eastern Carpathians of Romania*. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* <https://doi.org/10.1016/j.palaeo.2019.109390>.
- Feurdean, A. 2005, *Holocene forest dynamics in northwestern Romania*. *The Holocene*, 13, 435-446, <https://doi.org/10.1191/0959683605hl803rp>.
- Feurdean A., Galka M., Kuske E., Tantau, I., Lamentowicz, M., Florescu, G., Liakka, J., Hutchinson, S. M., Mulch, A. & Hickler, T., 2015. *Last Millennium hydro-climate variability in Central-Eastern Europe (Northern Carpathians, Romania)*. *The Holocene*, 25(7), 1179-1192, doi:10.1177/0959683615580197.
- Finsinger, W. & Tinner, W. 2006: *Holocene vegetation and landuse changes in response to climatic changes in the forelands of the southwestern Alps, Italy*. *Journal of Quaternary Science* 21, 243-58.
- Florescu, G., Hutchinson, S.M., Kern, Z., Mîndrescu, M., Cristea, I.A., Mihăilă, D., Łokas, E. & Feurdean, A., 2017. *Last 1000 years of environmental history in Southern Bucovina, Romania: A high resolution multi-proxy lacustrine archive*. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 473, 26-40, doi:10.1016/j.palaeo.2017.01.047.

- Gârbacea, V., Tanțău, I., Pop, O. & Benea, M.,** 2015. *First radiocarbon dating of landslides („glimee”) in Romania*. *Carpathian Journal of Earth and Environmental Sciences*, 10, 217 – 222.
- Geantă, A., Galka, M., Tanțău, I., Hutchinson, S.M., Mîndrescu, M. & Feurdean, A.,** 2014. *High mountain region of the Northern Romanian Carpathians responded sensitively to Holocene climate and land use changes: a multi proxy-analysis*. *The Holocene*, 23, 869-881, 10.1177/0959683614534747.
- Heiri, O., Lotter, A. F. & Lemcke, G.,** 2001. *Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results*. *Journal of Paleolimnology*. Springer, Dordrecht, London, Boston, 101-110.
- Hammer, Ø., Harper, D.A.T. & Paul D.R.,** 2001. *Past: Paleontological Statistics Software Package for Education and Data Analysis*. *Palaeontologia Electronica*, 4(1), 4, 9.
- Ionita, M., Scholz, P. & Chelcea, S.,** 2016. *Assessment of droughts in Romania using the Standardized Precipitation Index*. *Natural Hazards*, 81(3), 1483-1498, doi:10.1007/s11069-015-2141-8.
- IPCC,** 2014. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. In: Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White, L.L. (eds), Cambridge University Press, Cambridge, 1132.
- Jordan, W.C.,** 1996. *The Great Famine: Northern Europe in the Early Fourteenth Century*. Princeton University Press.
- Juggins, S.,** 2007. *C2 Version 1.5 User Guide. Software for Ecological and Palaeoecological Data Analysis and Visualisation*. Newcastle University, Newcastle upon Tyne, UK.
- Longman, J., Veres, D., Ersek, V., Salzmann, U., Hubay, K., Bormann, M., Wennrich, V. & Schäbitz, F.,** 2017. *Periodic input of dust over the Eastern Carpathians during the Holocene linked with Saharan desertification and human impact*. *Clim. Past*, 13, 897-917, <https://doi.org/10.5194/cp13-897-2017>.
- Luterbacher, J. & Pfister, C.,** 2015. *The year without a summer*. *Nature Geoscience*, 8(4), 246-248, doi:10.1038/ngeo2404.
- Mann, M.E., Zhang, Z., Rutherford, S., Bradley, R.S., Hughes, M.K., Shindell, D., Ammann, C., Faluvegi, G. & Ni, F.,** 2009. *Global signatures and dynamical origins of the Little Ice Age and Medieval Climate Anomaly*. *Science*, 326, 1256.
- Mitchell, E.A.D., Charman, D.J. & Warner, B.G.,** 2008. *Testate amoebae analysis in ecological and paleoecological studies of wetlands: past, present and future*. *Biodivers. Conserv.*, 17, 2115-2137, 10.1007/s10531-007-9221-3.
- Panait, A., Hutchinson, S., Diaconu, A-C., Tanțău, I. & Feurdean, A.** 2019. *Disentangling dust and sand deposition using a peat record in CE Europe (northern Romania): A multiproxy approach*. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 532, 109257, 10.1016/j.palaeo.2019.109257.
- Reimer, P.J., Austin, W.E.N., Bard, E., Bayliss, A., Blackwell, P.G., Bronk Ramsey, C., Butzin, M., Cheng, H., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Hajdas, I., Heaton, T.J., Hogg, A.G., Hughen, K.A., Kromer, B., Manning, S.W., Muscheler, R., Palmer, J.G., Pearson, C., van der Plicht, J., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Turney, C.S.M., Wacker, L., Adolphi, F., Büntgen, U., Capano, M., Fahrni, S.M., Fogtmann-Schulz, A., Friedrich, R., Köhler, P., Kudsk, S., Miyake, F., Olsen, J., Reinig, F., Sakamoto, M., Sookdeo, A. & Talamo, S.,** 2020. *The IntCal20 Northern Hemisphere Radiocarbon Age Calibration Curve (0–55 cal kBP)*. *Radiocarbon*, 62(4), 725-757, 10.1017/RDC.2020.41.
- Ruskal, A., Diaconu, A.D., Grindean, R. & Tanțău, I.,** 2020. *Early to mid-Holocene hydroclimate trends in the western Carpathians of Romania*. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 543, 109608, <https://doi.org/10.1016/j.palaeo.2020.109608>.
- Ruosteenoja, K., Markkanen, T., Venäläinen, A., Räisänen, P. & Peltola, H.,** 2018. *Seasonal soil moisture and drought occurrence in Europe in CMIP5 projections for the 21st century*. *Clim. Dyn.* 50, 1177, <https://doi.org/10.1007/s00382-017-3671-4>.
- Tămaș T., Onac B.P. & Bojar, A.-V.,** 2005. *Lateglacial-Middle Holocene stable isotope records in two coeval stalagmites from the Bihor Mountains, NW Romania*. *Geol. Quart.*, 49 (2), 185-194.
- Tanțău, I., Feurdean, A., De Beaulieu, J., Reille, M. & Fărcaș, S.,** 2014. *Vegetation sensitivity to climate changes and human impact in the Harghita Mountains (Eastern Romanian Carpathians) over the past 15 000 years*. *Journal of Quaternary Sciences*, 29, 141-152, doi:10.1002/jqs.2688.
- Tolonen, K., Warner, B.G. & Vasander, H.,** 1992. *Ecology of testaceans (Protozoa: Rhizopoda) in mires in Southern Finland. Autoecology*. *Archiv für Protistenkunde*, 142, 119-38.
- Whitlock, C. & Larsen, C.,** 2001. *Charcoal as a fire proxy*. In: Smol, J.P., Birks, H.J.B., Last, W.M. (Eds). *Tracking Environmental Change Using Lake Sediments*. Springer, Netherlands, 75-97.

Received: 21.08.2025
 Revised: 28. 11. 2025
 Accepted: 30. 11. 2025
 Published: 5.12. 2025