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THE COMPLEMENTARY USE OF CHARCOAL NUMBER AND MORPHOLOGY TO RECONSTRUCT FIRE HISTORY IN A LATE HOLOCENE PEAT SEQUENCE FROM NW ROMANIA

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Abstract: Fires influence basic ecosystem processes, including the distribution, the structure and the composition of vegetation, as well as the carbon cycle and climate at the global scale. Long-term knowledge (i.e., centuries or millennia) of fire regime history and forest fire ecology and dynamic in local environments is necessary for sustainable ecosystem management and biodiversity conservation strategies. Charcoal is a widely used proxy for reconstructing fire regime history and vegetation burning. Charcoal analysis is based on the accumulation of charred particles in depositional environments such as lakes and bogs, during and shortly after the occurrence of fire events. Ombrotrophic peat bogs are sensitive to local environmental changes and, given that the deposition of allochthonous material is exclusively atmospheric, they are ideal archives for reconstructing charcoal fluxes resulting from biomass burning. This study quantifies charcoal abundance (number) in a peat sequence extracted from Tăul Mare ombrotrophic peat bog (Văratec Massif, Lăpuş Mts, north-western Romania) aiming to reconstruct local fire history over the last 3000 years and to explore potential drivers. As a novelty, observations concerning the morphology of charred fragments are added to provide additional information on the type of material burnt (woody vegetation or herbs), fire severity and charcoal source area, thus strengthening the interpretation of the charcoal record. Results showed moderate fire activity between 3000 and 2300 cal yr BP, which slightly decreased between 2300 and 700 cal yr BP and varied considerably throughout the last 700 years. Several major fire episodes were further identified around 2500, 1700, 1300, 900 and 500 cal yr BP. Of these, the first four overlapped two phases of progressive landscape opening and extension of pastoral activities, while the latter was unprecedented in the entire history of the bog and was likely associated with the development of mining activities in the area. This study provides the first complementary use of charcoal morphologies in fire history reconstruction in Romania and adds a valuable perspective on the extent of past human impact on the mid-elevation mountain landscape.

Key words: charcoal number, charcoal morphologies, fire history, ombrotrophic peat bog, human impact, Late Holocene, Carpathians, NW Romania.

1. INTRODUCTION

Charcoal analysis of sediments from peat bogs and lakes is routinely used to reconstruct long-term variations in fire occurrence that can complement and extend information provided by historical records (Feurdean et al., 2015). Fire activity can be inferred from sedimentary charcoal records by examining total charcoal abundance (per unit of sediment), which was shown to be proportional to the total biomass burned (Marlon et al., 2009). In most cases, charcoal data from sediment cores are used to examine the linkages among fire and climate, vegetation, and sometimes anthropogenic activities of the past (e.g., Blarquez et al., 2015; Leys & Carcaillet, 2016; Vannière et al., 2016). The growing use of charcoal-based fire activity reconstructions over the last decade reflects an increased interest within the paleoecological scientific community to consider fire as an important ecosystem process operating on both long- and short-term time scales; it also highlights an increasing necessity of forest managers to understand past fire regimes in order to identify sustainable management strategies for present and future forested landscapes (Whitlock & Larsen, 2002; Whitlock et al., 2018). Numerous global studies employing the analysis of fossil charcoal reflect the need to understand past vegetation fires, especially during the late Holocene (Whitlock & Larsen, 2002, Whitlock et al., 2010). Late Holocene is a key interval for reconstructing past fire activity, because of a more enhanced human impact on the environment and the possibility to assess more accurately its influence on fire regimes (Rius et al., 2012).

Over the last 15 years, several papers have reviewed the methods used for charcoal analysis in lake-sediment and peat cores and its use as a tool for reconstructing fire history (e.g., Mooney & Tinner, 2011; Mustaphi & Pisaric, 2014). These studies show that the advantage of macroscopic charcoal fragments (> 90/150 µm) in the reconstruction of fire history is that they cannot be transported over long distances from their place of production and therefore may offer very accurate local reconstructions of the frequency, type and severity of the fire at the catchment scale (Whitlock & Anderson, 2003). Furthermore, the methods for analysing charcoal and processing the results have evolved over time (Mooney & Tinner, 2011) since their introduction and earliest applications in North America (Whitlock & Anderson, 2003). Presently, there are two main methods of quantifying macroscopic charcoal in peat and lake sediments: quantification based on charcoal number, and based on charcoal area, respectively. While using charcoal area may reduce the uncertainties in charcoal analysis resulting from taphonomic processes and breakage during sample preparation, it can also generate measurement errors due to very large, individual particles which cannot be associated to a fire event (Finsinger et al., 2014). Thus, charcoal area may be preferred in environments where taphonomic processes are deemed as important, such as the Mediterranean area (e.g., Leys et al., 2013). Conversely, taphonomic processes may be minimal in higher latitude environments and/or ombrotrophic bogs, where the charcoal number method is more suitable (Florescu et al., 2018; Mustaphi & Pisaric, 2014). Additionally, recent studies have shown that analysing the morphology of macroscopic charred particles may provide supplementary information regarding the type of material burnt (wood, grass, herbs) and may offer clues on changes in fire severity over time (Enache and Cumming, 2006, 2009; Mustaphi & Pisaric, 2014; Feurdean et al., 2017a).

However, to date very few studies in Europe used the quantification of abundance along with the assessment of morphological characteristics of macroscopic charred particles (e.g., Feurdean et al., 2017a; Marcisz et al., 2019), while there are no studies in Romania which have so far employed macroscopic charcoal morphologies in fire history reconstructions. Furthermore, there are only a few areas in Romania where fossil charcoal was used to reconstruct fire activity, and these areas are predominantly located at high altitude (Finsinger et al., 2018; Feurdean et al., 2012, 2017a, 2020; Florescu et al., 2017, 2018). Fire activity reconstructions at various elevations and in various vegetation areas/belts are used to improve the strategies of assessing past fire patterns and to test the strengths and limitations of the method in this region, thus contributing to a better understanding of charcoal as a fire proxy.

Here we provide the first complementary analysis of macroscopic charcoal number and morphology in Romania, aiming to reconstruct fire activity throughout the late Holocene and distinguish between fuel types. We use a ca. 3000-yr old peat sequence extracted from the Tăul Mare ombrotrophic bog located in the mixed forest belt of Lăpuș Mts, in the north-western part of the country. Our temporal focus, i.e., the last 3000 years, is of particular importance as it was characterized in the regional palaeoecological records by enhanced human land use (including forestry, agro-pastoral and mining activities etc.) that has disturbed natural fire regime patterns (e.g., Schumacher et al., 2016; Florescu et al., 2018).

This study has the following research objectives: (i) to complementarily quantify macroscopic charcoal number and morphologies in the Tăul Mare peat sequence; (ii) to use this data for reconstructing and contextualizing fire regime history and its possible drivers at the study site.

1.1. Charcoal production, transport, and deposition

Charcoal is produced when a fire, either natural or anthropogenic, incompletely combusts organic matter. The rate at which charcoal accumulates in a bog or lake depends on the characteristics of the fire (e.g., how much charcoal is produced), of vegetation (how much biomass is available to burn), the degree of the landscape openness at the time of burning and the processes that transport and deliver charcoal to the

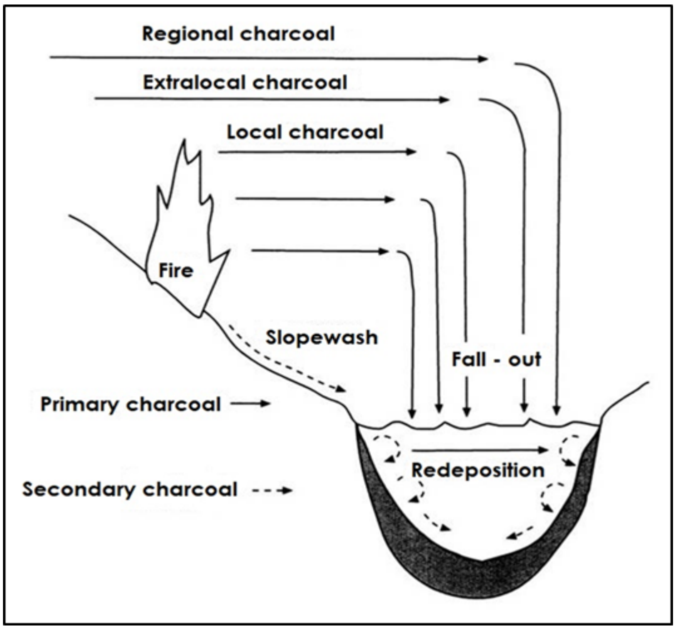

Figure 1. Schematic diagram illustrating the sources of primary and secondary charcoal in the watershed of a lake (Whitlock & Larsen, 2002).

peat bog or lake (Figure 1; Whitlock & Larsen, 2002).

As illustrated in Figure 1, primary charcoal refers to the material deposited in the lake/peatbog during or shortly after a fire event. Secondary charcoal includes the charcoal particles deposited in sediments during years with no fires originating in surface runoff and lake-sediment mixing inducing redeposition (Whitlock & Larsen, 2002). While in depositional environments such as fens runoff is reduced and mixing/redeposition are generally absent, in ombrotrophic bogs the primary charcoal, deposited via atmospheric fallout, is predominantly retained (Higuera et al., 2005). In the last several decades, numerous studies have used peaks in charcoal accumulation in sediment records to estimate the timing of “fire episodes” (Whitlock & Larsen, 2002). Recent studies have shown that, according to their size and shape, charcoal particles can be lifted to great heights and transported over great distances (e.g., Vachula et al., 2018). As such, the sources of the macroscopic charcoal fragments may be local fires (i.e., occurring within the watershed), extra-local fires (nearby but not within the watershed) (Gavin et al., 2003; Higuera et al., 2005) or even regional fires, if the fragments are smaller than 300 µm (Adolf et al., 2018; Florescu et al., 2018).

1.2. Characterisation of the study area and site

Tăul Mare (TG) peat bog (52°82´846.16´´N, 27°62´24.20´´E) is located in Văratec Massif, Lăpuş Mountains (Eastern Carpathians, northwestern Romania) at an elevation of ca. 1.066 m a.s.l. The bog is situated near Băiuț village, north of the Tăul Roșia UNESCO site, in the upper catchment of Lăpuș River (Figure 2). Morphologically, the medium altitude, intensely eroded volcanic range of Lăpuş Mts (Văratec Massif) accounts for 78% of the area, while the remaining 22% consists of hills and intermontane depressions (Badea et al., 2012). The prevalence of mountainous terrain within the study area further influences the other elements of the natural environment, such as: climate, hydrography, vegetation and fauna. Climatically, Văratec Massif is characterized by moderate continental conditions typical for mid-elevation mountains, with Atlantic and Baltic influences (Stoenescu & Tistea, 1962). The mean annual temperature is 4-8°C (-4 to -6°C in January, 12-16°C in June), while the mean annual precipitation varies around 1200-1400 mm, evenly distributed between seasons (Badea et al., 2012). The bog vegetation is composed of *Sphagnum* and *Polytrichum* alongside *Poaceae* and *Carex*, whereas catchment vegetation comprises *Picea abies* (L.) H. Karst. with *Salix cinerea* L., *Vaccinum myrtillus* L., *Sorbus aucuparia* L. and *Rubus* sp., as well as herbaceous plants such as *Homogyne alpina* (L.) Cass., *Eriophorum* sp., *Drosera rotundifolia* L., *Molinia caerulea* (L.) Moench, *Lycopodium annotinum* L., *Dryopteris remota* (A. Braun) Hayek, *Carex* sp., *Phegopteris connectilis* (Michx.) Watt etc. (Peters et al., 2020). Regionally and in the catchment of the study site, the dominant vegetation types pertain to the mountain mixed forest belt, where *Fagus sylvatica* L. and *Abies alba* Mill. stands are often mixed with spruce. The latter species can form pure stands in the subalpine level (*Homogyno-Piceetum*), as it is the case above the peat bog. Open mountain heaths are also present due to recent clearings (Badea et al., 2012).

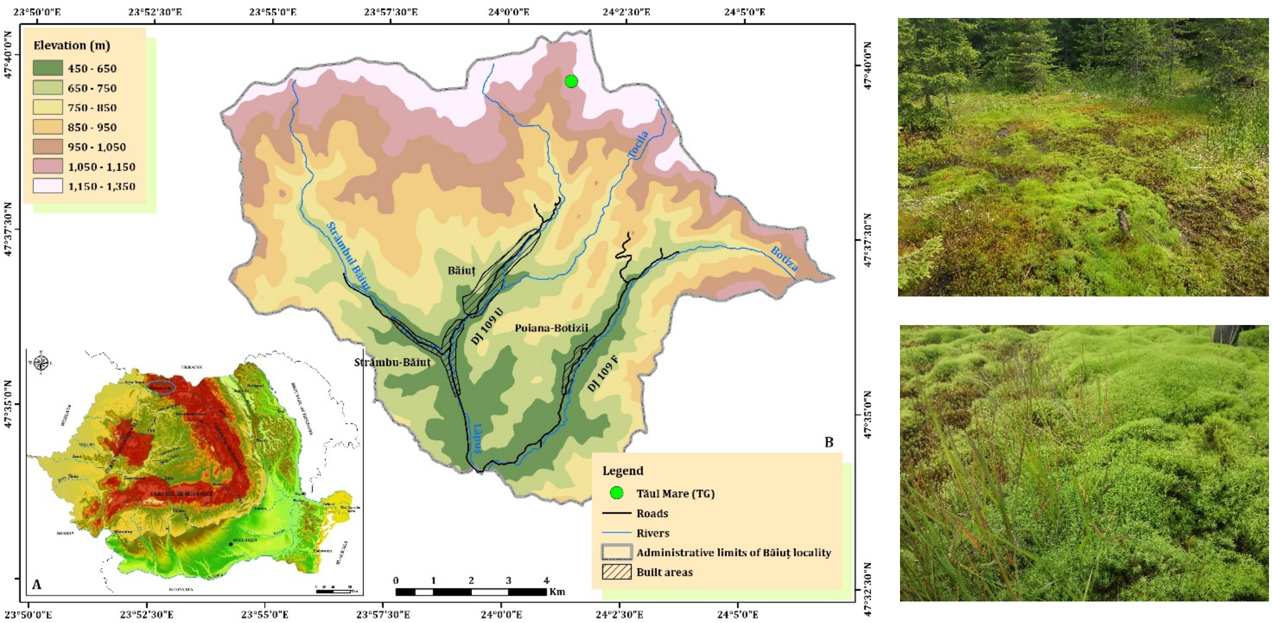

Figure 2. Location of Tăul Mare (green dot) in the upper catchment of Lăpuș River, and in NW Romania (insert). Photos on the right side (top and bottom) show vegetation at the coring point.

2. MATERIALS AND METHODS

2.1. Chronology

A 221 cm-long peat core of was extracted from the Tăul Mare ombrotrophic bog in 2017 using a Russian corer with a chamber length of 60 cm and width of 8 cm. The chronology of the peat accumulation was constructed based on 4 selected samples (Table 1) which were measured by accelerator mass spectrometry (AMS) using the facilities of the Isotoptech Zrt Radiocarbon Dating Laboratory in Debrecen (Hungary) and Beta Analytics Radiocarbon Dating Laboratory in Miami (Florida, USA). Calibration of 14C dates to calendar years was performed using the INTCAL20 dataset (Reimer et al., 2020). The age-depth model was constructed using the smoothing spline method provided by the CLAM package in R (Blaauw, 2010). The top centimetre of living peat was assigned to the year 2017 (year of coring) and included in the model.

2.2. Quantification of the abundance (number) of macroscopic charcoal

Samples of 2 cm^3 each were extracted continuously at 1 cm intervals along the peat profile. The samples were bleached for 24 hours and wet-sieved using a 150 µm mesh size. All macro-charcoal particles retained in the sieve were counted using a stereomicroscope at 30x magnification (Whitlock & Larsen, 2002; Feurdean et al., 2017b). Macro-charcoal counts were expressed as concentration (particles/cm^3) by dividing charcoal counts by sediment volume. Charcoal concentration was further normalized by dividing it by peat accumulation rate (yrs/cm) as derived from the age-depth model, to obtain the charcoal accumulation rate or charcoal influx (particles/cm^2/yr) (Marlon et al., 2016). To facilitate description of the results, the charcoal accumulation record was further divided into three distinct units using stratigraphically constrained cluster analysis based on Chord distance in PAST software (Hammer et al., 2001).

2.3. Analysis of charcoal morphology

Each individual macro-charcoal particle was examined under the stereomicroscope (magnification 40x) and grouped according to its morphological features based on the classifications of Mustaphi & Pisaric (2014) and Enache & Cumming (2006). As such, bulky morphotypes that were lignified and with identifiable cell structure were assigned to burnt wood and woody material, elongated and porous morphotypes with parallel cell structure and stomata rows were classified as burnt grass (*Poaceae*), whereas fragments not corresponding to either of the aforementioned categories were included in the category of forbs and other herbaceous fragments (Feurdean et al., 2017a). The identified morphotypes, separated according to the three generalized categories corresponding to wood, grass, and forbs, are also rendered as accumulation (influx values).

3. RESULTS AND DISCUSSION

3.1. Core chronology, age-depth model and peat accumulation rate

Radiometric results for the sample taken 9 centimetres above the lower limit of the extracted peat profile showed an age of 2733 ± 30 calibrated years BP (95.4% probability) (Table 1). By using terrestrial macro-remains (i.e., conifer needles) as dating material, the accuracy of the results was maximized. Subsequently we extrapolated the obtained age to the depth of 221 cm, in the absence of any lithological transitions, and showed that the extracted peat profile spans the last ca. 2950 years (Figure 3). However, coring did not reach the base of the peat layer, which suggests that the timing of peat formation may go beyond the Late Holocene.

Based on the obtained age-depth model (Figures 3 and 4), peat accumulation rate varied between 8 and 20 years/cm over the last 2950 years. These values are tentative, however, as our model is based only on four dating points. The interval with the lowest peat accumulation rate (more than 15 years/cm) occurred between ca. 2100 and 900 cal yr BP. This interval corresponds in local published palaeoclimatic reconstructions with warmer than average and relatively drier climatic conditions (e.g., Diaconu et al., 2017; Schnitchen et al., 2006), overlapping the influence of specific climate shifts such as the Roman Warm Period (2200-1600 cal yr BP) and the Medieval Warm Period (1100-800 cal yr BP). Conversely, the highest peat accumulation rate (less than 10 years/cm) was documented between 2950-2500 cal yr BP, when reconstructed climate conditions were cooler and moister (Diaconu et al., 2017; Schnitchen et al., 2006). Altogether, climate conditions appear to explain the main trends in peat accumulation rates at the study site.

3.2. Charcoal concentration and influx

Charcoal concentration (CHAC; particles/cm^3) was converted to charcoal accumulation rate or influx (CHAR; particles/cm^2/yr) based on the peat accumulation rate derived from the age-depth model (see section 2.2 in *Materials and methods* for details). Stratigraphically-constrained cluster analysis applied

Table 1. The radiocarbon data from Tăul Mare peat bog

Lab code	Depth (cm)	^{14}C age (years BP)	Calibrated age years AD/BC (2σ)	Median age (cal yr BP) (2σ)	Sample type
DeA-28361	91	1146 ± 28	AD 775 - 990	1167	Conifer needles
DeA-28361	133	2076 ± 27	BC 171 - AD 5	1972	Twig
Beta-483484	147	2220 ± 30	374 - 202 BC	2220	Wood
DeA-28361	212	2733 ± 30	930 - 810 BC	2853	Conifer needles

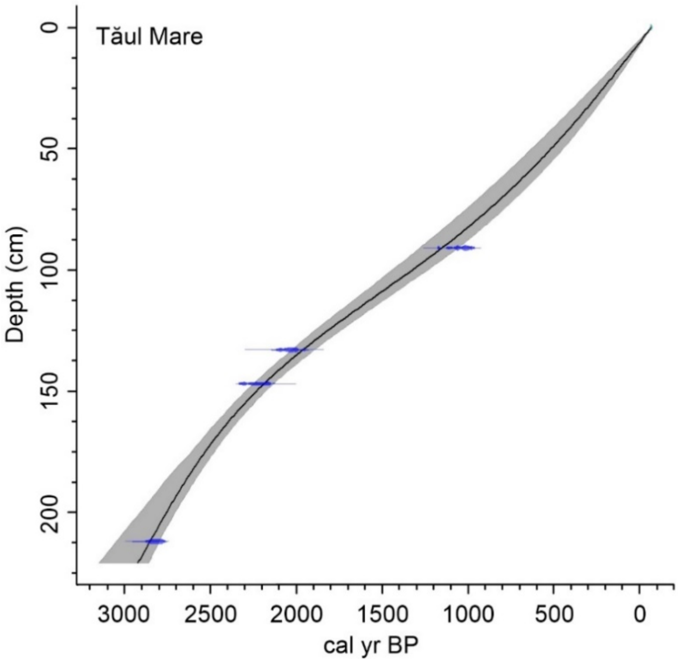

Figure 3. Age-depth model at Tăul Mare (TG). Data points used for the construction of the age-depth model (blue).

on charcoal influx data allowed for the separation of three main units: Unit I between 2950 and 2300 cal yr BP, Unit II between 2300-700 cal yr BP, and Unit III representing the last 700 years. As illustrated in Figure 4, the peat accumulation rate slightly influenced CHAC in units I and II, hence the transformation of CHAC to CHAR provided a more accurate reconstruction of fire activity in these units.

Charcoal accumulation was variable throughout the last 3000 years. Moderate charcoal influx was specific for units I and II, with well-defined peaks around 2500, 1700, 1300 and 900 cal yr BP (Figure 4). According to Higuera et al., (2005), charcoal peaks where the concentration averages to at least 10 fragments/cm^3 are considered statistically reliable indicators of the occurrence of fire episodes (a fire episode is defined as one to several fire events which occurred within the time window of the temporal resolution per sample). All identified charcoal peaks in our record fulfil this requirement. Conversely, Unit III displayed the lowest overall charcoal influx values, with the exception of a very prominent charcoal peak around 500 cal yr BP, which is the largest documented in the entire record. However, the overall low charcoal concentration during this particular event (up to 50 fragments/cm^3) further suggests that there was no direct fire on the bog surface. Observations made during particle counting showed an increase in the size of charred fragments during this major fire episode (i.e., more fragments >500 um), suggesting the occurrence of fires closer to the study site and/or a change in fire severity (e.g., from surface to crown fire). As a rule, experimental studies and model simulations revealed that large charcoal fragments were more abundant in the areas directly affected by fire or close to the burnt area (Ohlson & Tryterud, 2000; Clark, 1988). On the other hand, high severity forest fires were shown to produce larger size charcoal fragments deposited as far as several kilometres from the burning site (Tinner et al., 2006; Conedera et al., 2009).

3.3. Charcoal morphologies

The most frequent charcoal fragments found at Tăul Mare pertained to the elongated morphotypes, which are typically associated with burnt forbs and grasses. Regarding several elongated and very thin fragments (type D1 in the classification of Mustaphi & Pisaric, 2014), the accurate identification of the burnt material was difficult, as this morphotype can either result from the burning of grass leaf veins and awns or can consist of rays and tracheids originating from burnt wood (Mauquoy & Van Geel, 2007; Schweingruber, 1978). These fragments were also assigned to the grass category. However, the elongated shape of these fragments, corroborated with low weight and high portability, may imply their transport over a larger distance, i.e., extra-locally (Enache & Cumming, 2008).

Results also show that charcoal morphotypes associated with forbs were the most abundant in the entire profile (Figure 4). Conversely, morphotypes of grass charcoal were the least abundant. Bulky morphotypes, foliated and lignified, associated with woody biomass (Mustaphi & Pisaric, 2014), were also present along the profile. The bulky, often 3-d shape and larger weight of woody charcoal suggests a shorter transport distance from the charcoal source area and therefore may be regarded as a reliable indicator of the local burning of wood. Moreover, a rise in the proportion of woody charcoal, associated to increased burning of woody biomass, may also suggest a surge in fire severity, i.e., transition towards stand-replacing fires (e.g., Feurdean et al., 2017a). Five main peaks in woody morphotypes were detected in the Tăul Mare macro-charcoal profile,

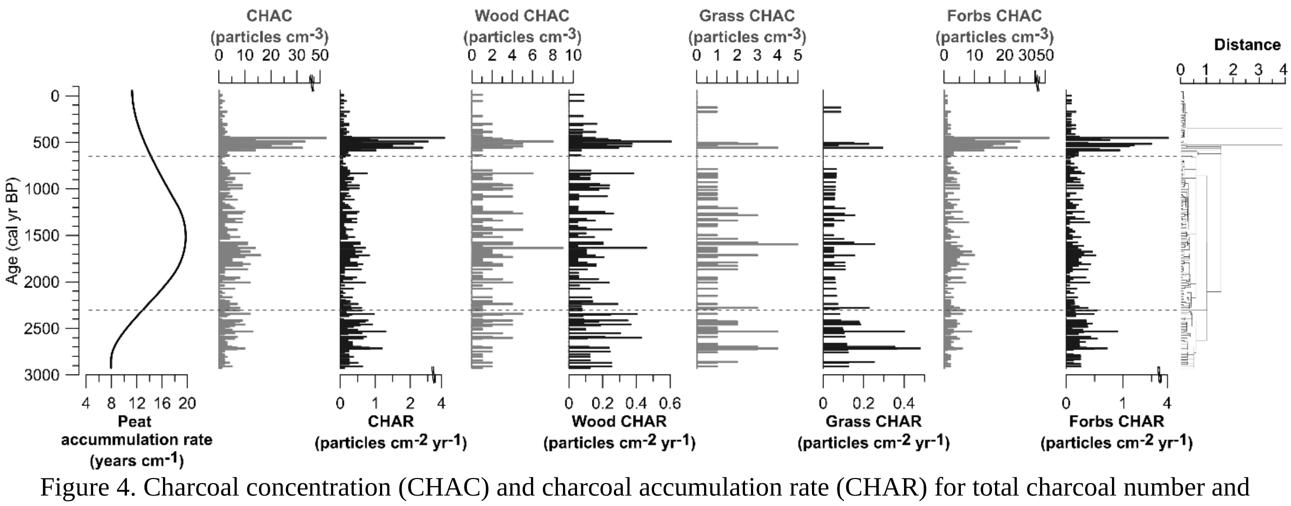

Figure 4. Charcoal concentration (CHAC) and charcoal accumulation rate (CHAR) for total charcoal number and morphologies.

which coincided with peaks in the total charcoal influx: around 2500, 1700, 1300, 900 and 500 cal yr BP (Figure 4), likely indicating that the corresponding fire episodes occurred closer to the site catchment. Of these, the proportion of woody morphotypes increased more evidently during the peak documented at 500 cal yr BP, suggesting that during this particular fire episode, fire occurrence was the closest to the study site and, given the corresponding increase in all morphotypes, further showing that the severity of fires in the study area likely increased to unprecedented levels.

3.4. Fire history over the last 3000 years reconstructed from charcoal data and published palaeoecological records

The Tăul Mare macro-charcoal record showed variable fire activity throughout the last 3000 years in the mixed forest belt of Lăpuș Mts. Specifically, between 2950-2300 cal yr BP (Unit I), there was moderate local-scale burning, and the peak fire activity occurred around 2500 cal yr BP. Local published vegetation reconstructions showed major changes in tree cover during this interval, with beech replacing spruce as the dominant forest taxon (Peters et al., 2020; Feurdean et al., 2008). Pollen of tree species associated with disturbances (such as birch, alder and pine) increased around 2500, along with the proportion of grasses and herbaceous taxa indicative of grazed meadows (Peters et al., 2020; Feurdean et al., 2001, 2008). At a larger spatial scale, high fire activity as inferred from microscopic charcoal record and early signs of cultivation at lower elevations were also present (Peters et al., 2020; Feurdean et al., 2009; Feurdean & Astalos, 2005; Farcas et al., 2013). Given that climate conditions derived from published records were cooler and moister than average during this interval (Diaconu et al., 2017; Schnitchen et al., 2006; Feurdean et al., 2008), it can be inferred that the increase in fire activity at the study site was most likely associated with an incipient expansion of human land use in the area.

Between 2300-700 cal yr BP (Unit II) a slight overall decrease in fire activity was observed, with several smaller fire episodes detected around 1700, 1300 and 900 cal yr BP. According to published palynological records, the proportion of tree species associated with disturbances, along with pollen of cultivated plants and grazed meadows, further increased regionally during this interval, against the backdrop of gradual landscape opening (Peters et al., 2020; Feurdean et al., 2009; Feurdean & Astalos, 2005; Farcas et al., 2013). Thus, the low intensity, more frequent fires documented in our record during this time interval are likely associated with the use of fire for the management of more remote, open grazing areas, as the timing coincides with similar developments across the Carpathians which were attributed to anthropogenic changing of the landscape (Geantă et al., 2014; Feurdean et al., 2017b; Florescu et al., 2018; Tanțău et al., 2011, 2014; Schumacher et al., 2016). Published palaeoclimatic data appear to indicate that warmer climate conditions predominated regionally (Diaconu et al., 2017; Schnitchen et al., 2006), which likely promoted an extension of anthropogenic activities, particularly crop cultivation at lower elevations. However, the large proportion of pollen of old-growth forest constituents such as beech and spruce (close to 80-90%) at Tăul Negru, located ca. 5 km from our study site (Peters et al., 2020) suggests that the study area remained forested and under low human impact (probably consisting of low intensity forest grazing and/or forest management practices reducing the negative effect of wood harvesting) throughout the Unit II period.

Over the last 700 years (Unit III), the background fire activity was the lowest documented in the Tăul Mare profile (Figure 4), with the exception of a singular fire episode at 500 cal yr BP, which was unprecedented in terms of magnitude in the entire known history of the peatbog. This episode most likely occurred in the catchment of the study site, but did not directly affect the bog surface, as inferred from the amount and larger size of the charred particles. Furthermore, the abundance of woody morphotypes indicates that wood was an important fuel during this fire episode. In the local to regional pollen records the last 700 years are characterised by a further intensification of anthropogenic indicators, most notably the prominent, abrupt increase in landscape openness and in the proportion of pollen of both cultivated plants and weeds (Peters et al., 2020; Feurdean et al., 2009; Feurdean & Astaloș, 2005; Fărcaș et al., 2013). Fire activity also increased regionally from 500 cal yr BP onward (e.g., Peters et al., 2020; Feurdean et al., 2009, 2012, 2015; Florescu et al., 2017). This suggests that the fire episode detected at 500 cal yr BP in our record was likely connected with a larger scale driver, such as climatic conditions and/or extensive anthropogenic activities. From the perspective of human land use and impact, archaeological and documentary evidences depict an expansion of mining in the area (Borcoș & Udubașa, 2012; Py-Saragaglia et al., (2020), and the peat geochemistry in our profile (unpublished data) clearly shows a prominent peak in trace metal pollution associated with atmospheric deposition from mining and ore smelting. We may therefore infer that mining activities probably expanded at regional scale, as mining operations generally use burning around ore deposits to clear-off vegetation for exploration. The development of mining was also likely associated with an increase in population and agro-pastoral activities which may result in clearing. Additionally, fire may have also been used for the local production of charcoal for ore smelting. Regarding the climatic conditions, the fire episode documented at 500 cal yr BP overlaps the cold and moist period known in the climate history as the Little Ice Age (LIA), which is well represented in various palaeoclimatic proxy records across the Carpathians (Diaconu et al., 2017; Schnitchen et al., 2006; Feurdean et al., 2008, 2015), further supporting the hypothesis that this fire episode was of anthropogenic origin. The changes documented in fire activity in our record (i.e., peak fire activity around 500 years ago, ensued by a lack of fire episodes in the following centuries) overlapped the cold and moist Little Ice Age period and the warming thereafter, suggesting that over the last 700 years human impact became prevalent compared to climate in terms of shaping the fire regime in this area. These conclusions are also supported by findings on a larger spatial scale for the Central European Lowlands (e.g., Dietze et al., 2018).

4. CONCLUSIONS

It is predicted that in the upcoming years the threat of wildfires will increase even in regions previously considered to be beyond threat, such as the mid elevation mountain ranges of the Eastern Carpathians, resulting in costly environmental and economic consequences. Hence, more charcoal-based studies in this area are necessary for a better understanding of local fire histories.

Our charcoal-based reconstruction of fire activity in the mixed forest belt of Lăpuș Mountains spanned most of the Late Holocene, a period which has been increasingly shaped by the human transformation of the landscape. Results showed moderate burning between 3000 and 2300 cal yr BP, moderate to low burning between 2300 and 700 cal yr BP, and varying fire activity over the last 700 years. Based on the peaks determined in charcoal concentration and influx, added to morphological characteristics, we identified several major fire episodes around 2500, 1700, 1300, 900 and 500 cal yr BP. Of these, the first four overlapped a period of progressive landscape opening and extension of pastoral activities, while the latter episode showed an unprecedented magnitude in the time frame spanning three millennia of the bog history and was likely associated with the development of mining activities in the area.

Our results showed that a combined methodological approach of macroscopic charcoal analysis in sedimentary sequences (based on number and morphology of charred fragments) has the potential to add key information regarding fuel type, fire severity and charcoal source area in the interpretation of charcoal records. Such an approach, backed up by a robust age-depth model, is a prerequisite step for a further reconstruction of more quantitative fire metrics.

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